EFFECT OF SHIFTING FREQUENCY ON LIVEWEIGHT GAIN OF
GRAZING STEERS

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN AGRONOMY AND SOIL SCIENCE

DECEMBER 1988

By

Andres Alvarez de la Roche

Thesis Committee:

Peter P. Rotar, Chairman
Burton Smith
Rusell Yost

We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy.

THESIS COMMITTEE

Peter P. Rotar

Chairman

Russell Yost

ACKNOWLEDGEMENTS

I would like to express my gratitude to my Thesis Committee, in particular, to Dr. Burt Smith for his teaching of pasture management and for the good laughs.

I would also like to thank the members of the Mealani Experiment Station crew for their assistance with the field work and Ruth Niino-DuPonte and Dr. James Carpenter for their help with the in vitro digestibility analyses.

Special thanks to my brother Santiago Alvarez and Pamela Mills-Packo for their encouragement in the early days and to Janet Schultz for her friendship and valuable assistance.

ABSTRACT

Two trials lasting approximately two months each were carried out with different groups of holstein steers each initially weighing ≈150 kg. Three shifting frequency treatments with no replications were imposed: three day, once daily and twice daily. Pasture allowances (kg DM animal^{-1} day^{-1}) varied throughout the trials but remained equal among treatments.

No significant differences in liveweight gain were observed among treatments. Higher shifting frequency treatments showed a tendency to have higher liveweight gains when gains were ≈650 gm animal^{-1} day^{-1} or lower. It is recommended that future studies monitor the effect of shifting frequencies on pasture growth. Under the conditions of this study satisfactory estimates of kikuyugrass (*Pennisetum clandestinum*) were not provided by use of a capacitance meter or plant height.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADG	Average Daily Gain
CP	Crude Protein
CV	Coefficient of variation
DMD	Digestible dry matter
IGM	Intensive Grazing Management
IVDDM	_In_ _Vitro_ Digestible Dry Matter
LWG	Liveweight Gain

I. INTRODUCTION

Intensive Grazing Management (IGM) is widely used in Hawaiian ranches. The first grazing cell started operation in 1982. By 1986 over 10,000 ha (25,000 A) had been placed into intensive grazing (Smith et al., 1986).

The practice of IGM involves the shifting of animals among paddocks at least during a portion of the grazing season. Although the effect of different animal shifting frequencies has been studied abroad, little information is available on the effect of shifting frequency *per se* on animal liveweight gain. Studies with pen-fed animals showed that as feeding frequency increased, so did the efficiency of food utilization and average daily gain (ADG)(Gibson, 1981).

These trials were conducted to test if under grazing conditions and with equal pasture allocations, higher shifting frequencies would result in higher liveweight gains. Two methods of pasture yield determination (capacitance meter and pasture height) were evaluated on kikuyugrass pastures.

II. LITERATURE REVIEW

1. Intensive Grazing Management

a. basic principles

Intensive Grazing Management is a pasture management approach that utilizes different grazing strategies, including but not limited to, rotational grazing that, depending upon condition, may be either long or short duration grazing, high or low frequency, or any combination thereof.

IGM uses some of the basic principles of rotational grazing described by Voisin (1959). Rotational grazing allows the major portion of the grazing area to be rested while only a small portion is being grazed. Voisin (1959) suggested that the grazing period should be no longer than four days so that no regrowth was available for grazing during the same period as this would exhaust the plant reserves and result in degraded pastures. The resting period should also be long enough for plants to accumulate reserves necessary for regrowth. The resting period, therefore will be shorter during periods of active growth and longer when pasture growth slows down (Voisin, 1959; Savory and Parsons, 1980; Smith et al., 1986). When the current grazing is completed, the amount of forage remaining should be such that there is little rank pasture left other than in places where dung and urine have been excreted. By reducing animal selectivity and leaving little rank pasture behind, it is expected that all of the pasture will be of high quality when the animals graze it the next time (Smetham, 1973).

Properly practiced rotational grazing was shown to increase the amount of pasture produced and subsequently stocking rates (Hayman and Saville, 1981; McMeekan and Walshe, 1963; Walton et al., 1981). Higher pasture productivity was attributed in part to a higher photosynthetic efficiency of the sward. Longer resting periods between defoliations experienced under rotational grazing allow for a larger leaf area index (LAI) to be achieved before grazing and consequently more light is utilized in photosynthesis. There is a point where the shading effect and the age of the leaves result in a decrease in net photosynthesis (Bryant et al., 1970). Korte (1982) demonstrated that dead herbage and stems in rank pasture intercept considerable amounts of light, shading photosynthetic tissue. Presence of rank stemy pasture can result in lower liveweight gains (Lewis and Collen, 1973, as cited by Korte, 1982).

Benefits from higher forage production can only be obtained at stocking rates where the animals' appetite begin to exceed grass supply. If the animals' appetite is satisfied by the amount of forage on offer, then there will be very little difference between continuous and rotational grazing (Ruane and Raftery, 1964). It is a recommended practice to increase stocking rates with intensive grazing (Savory and Parsons, 1980). This increase in stocking rate will result in higher animal output per hectare since stocking rate is more influential on per hectare productivity than any other factor, including grazing systems (Wheeler, 1962).

Bircham and Korte (1984) indicated that few experiments comparing rotational versus continuous grazing have shown higher dry matter production under rotational grazing. They concluded that even when differences were found it was impossible to determine whether these differences were due to increased new growth or reduced disappearance resulting from increased utilization. Smetham (1973) attributed the higher animal production from rotational grazing to higher total digestible nutrients per hectare and not higher dry matter yields.

Apart from the effects on pasture growth, rotational grazing also provides the manager with more control over the performance of livestock (Bircham and Korte, 1984). He does this by improving the match between pasture supply and livestock demand throughout the year (Sheath and Bryant, 1984). Control of animal productivity provided by rotational grazing is accomplished through the use of subdivisions. By dividing the field and concentrating the animals in smaller paddocks the manager can estimate and plan pasture intake levels and animal performance. Some researchers oppose any practice of rotational grazing in tropical pastures for increasing liveweight gain per hectare (Mannetje et al., 1976; Morley, 1981; Whiteman, 1980) except with special forages like *Leucaena leucocephala* (Mannetje et al., 1976). Subdivision in this case is only considered as a means of separating different kinds of livestock and performing cultural practices like tick and weed control and forage conservation. Control of livestock obtained from rotational grazing is attributed to the farmers' desire to "feel in control" of their pastures rather than any advantages of the grazing method itself (Morley, 1981). On the Island of Hawaii however, a case study with a 28-paddock cell located on Kahua ranch showed a dramatic increase in per-acre productivity of kikuyugrass pastures. After a year of operation, productivity had increased from 280 kg ha^{-1} $year^{-1}$ (250 lbs A^{-1} $year^{-1}$) to approximately 812 kg ha^{-1} $year^{-1}$ (725 lbs A^{-1} $year^{-1}$) without the use of fertilizers (Leung and Smith, 1984).

b. subdivision

Subdivision is the most economical method of obtaining the desired control in a grazing operation (Smith et al., 1986). It aids in keeping different kinds of livestock separate and promotes better pasture utilization on areas of the farm with less palatable species (Squire, 1985). As the number of pastures increases so does the proportion of the resting period although at a diminishing rate (Smith et al., 1986). By concentrating the animals in a small area the manager can determine the amount and quality of the pasture eaten by his livestock. This provides him with an opportunity to accumulate and transfer forage to critical periods in his production scheme such as early lactation and pre-mating. The easiest way to accumulate and transfer forage is by concentrating the animals into mobs and grazing to low pasture residuals in short grazing periods of 1-5 days. For cattle the suggested animal density is between 150-200 head ha^{-1} (Sheath et al., 1987). Short grazing as opposed to longer grazing periods will reduce the fluctuation in quantity and quality of the forage eaten by livestock.

Sheath (1982), provided ewes with the same pasture allocation of 2 kg $animal^{-1}$ day^{-1} but varied the grazing length from three to fifteen days. He demonstrated that as grazing length increased, desired pasture residuals were reached earlier. A risk involved with using longer rotations is that managers might tend to rotate the animals too soon. This may be an unsound practice if forage supply is limited; however, the same researcher stated that "as grazing durations are shortened, the system and its manager, as opposed to the grazing animal, exerts an increasing amount of control on the allocation and utilization of pasture".

Subdivision may influence the feeding frequency of fresh feed of grazing animals (Smith et al., 1986). Under short rotations the animals are given fresh feed more frequently resulting in a more even feed intake. In contrast, low feed intakes are experienced in the later part of the grazing period of longer rotations. Smith et al. (1986) stated that frequent shifting may increase feed intake by as much as 20%. Several experiments with strip grazing milk cows, however have shown a little (Holmes and El Sayed Osman, 1960) or no difference in forage intake (Arnold and Holmes, 1958) and no difference in milk production over free grazing cows. Several experiments in New Zealand failed to show advantages in milk production from shifting every twelve hours (Smetham, 1973). Even if total feed intake is similar under different shifting frequencies it is possible that the increase in the feeding frequency of fresh forage with shorter grazing periods may increase the liveweight gain of young grazing animals. Experiments with pen-fed animals have shown higher liveweight gains as feeding frequency increases.

2. Feeding frequency and liveweight gain of ruminant animals

Effect of frequency of feeding on animal productivity has been studied with different kinds of ruminant animals. Review of the literature about pen-fed animals indicates a higher animal productivity is achieved as feeding frequency is increased (Gordon and Tribe, 1952; Mochrie et al., 1956; Putnam et al., 1961; Rakes et al., 1957). Animal response to increased feeding frequency seems to be related to age. Rakes et al. (1961) reported that increased feeding frequencies had no effect on the rate of weight gain of mature animals, but was advantageous with growing animals. In contrast, Clark and Keener (1962) and Hillier et al. (1968) did not find any differences in liveweight gain due to feeding frequency. Gibson (1981) analyzed published results of effects of feeding frequency on the growth of ruminant animals and concluded that increased feeding frequency increased the ADG of experimental animals. Increased ADG was attributed largely to increases in the efficiency of feed utilization. If this increase in efficiency of feed utilization is also present in grazing animals, an increase in level of subdivision would result in shorter grazing periods and increased liveweight gains.

3. Kikuyugrass (*Pennisetum clandestinum*)

a. Origin and distribution

Kikuyugrass is a widely adapted C4 grass originally from the Great Rift Valley of Africa (Urata, 1981) where it occurs naturally at elevations between 1950-2700 m with an annual precipitation of 1000-1600 mm (Mears, 1970). Minimum and maximum temperatures in its natural habitat range between 2-8 ^{o}C and 16-22 ^{o}C respectively (Morrison, 1969). Productive kikuyugrass pastures have been developed throughout the tropics and subtropics with similar climatic conditions (Mears, 1970).

b. Morphology

Kikuyugrass is an aggressive, creeping, perennial grass which spreads by means of seeds, rhizomes and stolons. Stolons and rhizomes root strongly at the nodes (Quinlan and Shaw, 1975). Young upright culms provide the bulk of forage and occasionally develop reproductive organs (Urata, 1981). Lodging occurs when plant height is approximately 45 cm (Whitney, 1974b). If kikuyugrass is allowed to grow old the stolons form a woody mat (Urata, 1981) which is undesirable under grazing.

c. Presence in Hawaii

Introduction of this species into Hawaii took place in 1925 (Hosaka, 1958). Since then, different cultivars have been introduced and evaluated in the state (Urata, 1972). Kikuyugrass is now a dominant pasture species in approximately 80,000 ha. It can be found from sea level to over 1,500 m of elevation although its growth is reduced at the higher elevations (Whitney, 1974a). Grazing is by far its major use in Hawaii but in other places it is used for erosion control (Quinlan and Shaw, 1975; Whiley, 1985).

d. Establishment

Kikuyugrass has been traditionally established from stem cuttings of 2 or 3 nodes in length. Sprigs can be broadcasted and disked in mechanically. If sprigs are scarce they can be placed in furrows (Quinlan and Shaw, 1975). Commercial seed has been available since the development of a feasible seed production technique by Wilson (1970). Recommended seeding rate is 1 kg ha^{-1} which should be drilled or broadcast and covered to 1-2 cm ensuring a good soil-seed contact (Quinlan and Shaw, 1975). Establishment occurs where seeds germinate in dung-pats (Hosaka, 1958; Mears, 1970; Wilson and Hennessy, 1977). Turf sowing (propagation of grass by laying strips of sod) has also proven satisfactory when a quick cover is desired (Quinlan and Shaw, 1975). In the hill country area of Northland (New Zealand), turf sowing is used to introduce kikuyugrass into ryegrass-clover pastures. Establishment was improved when the turfs were fertilized and particularly when competition was minimized by spot-spraying with a herbicide like paraquat. Sowing of turfs is an ideal alternative in areas where cultivation is not possible (Piggot and Morgan, 1985).

e. Flowering

Flowering stems have 2-4 flowers which are almost entirely enclosed in the leaf sheath of short side shoots (Hosaka, 1958). The only visible parts of the inflorescence are the stigma and, where present, the anthers, which are only 4.5 cm long (Quinlan and Shaw, 1975). Anthers of male sterile strains are retained in the leaf sheath and contain no viable pollen (Younger, 1961). Removal of the vegetative apex in this indeterminant grass is necessary for floral induction (Carr and Ng, 1956). Because of this characteristic, grazing or cutting stimulates flowering (Humphreys, 1981; Quinlan and Shaw, 1975). Repeated cuttings at increasing heights are used in seed production to increase seed yield per hectare (Wilson, 1970). Flowering does not appear to be related to daylength (Quinlan and Shaw, 1975).

f. Temperature response

Kikuyugrass has been classified as one of the most cold tolerant tropical grasses (Ivory and Whiteman, 1978a; Mannetje and Pritchard, 1974; Nada, 1980). It will not survive continuous frosting, however light frosts only dry-out exposed herbage (Mears, 1970). Nada (1980) compared the growth of 15 tropical grasses at day and night temperature regimes of 20-15 ^{o}C and 25-20 ^{o}C respectively. Setaria sphacelata and P. clandestinum had the highest capacity to maintain growth at the lower temperatures. Nada (1980) reported a low response of kikuyugrass to an increase in temperature from a 25-20 ^{o}C to a 30-25 ^{o}C regime. Ivory and Whiteman (1978a) reported a relative growth of kikuyugrass at temperatures of 10-15 ^{o}C similar to that of Chloris gayana and Panicum coloratum. Growth of these grasses were higher than that of Cenchrus ciliaris and Panicum maximum. Slow growth of kikuyugrass at low temperatures is due to a reduction in leaf size that is not compensated by a higher rate of leaf appearance (Ivory and Whiteman 1978a). Estimated critical mean daily temperature causing growth cessation was 8 ^{o}C. However, with a day temperature of 20 ^{o}C the critical night temperature was less than 4 ^{o}C (Ivory and Whiteman,

1978b). Kemp (1974, as cited by Ivory and Whiteman 1978b) observed growth of kikuyugrass in the spring only when mean daily temperatures reached 13-15 ^{o}C. The same study reported growth cessation to occur at 12-14 ^{o}C in the fall and in one case where there was a gradual decline in mean daily temperature growth ceased at 6-12 ^{o}C. Low day temperatures not only reduced growth but also stimulated tillering (Ivory and Whiteman, 1978a, Mannetje and Pritchard, 1974).
Optimum maximum 12-hour day and night temperatures for total plant growth of kikuyugrass are 29.4 and 25.6 ^{o}C respectively (Ivory and Whiteman, 1978a). Ezumah (1970) and Mitchel (1956 as cited by Korte et al., 1987) also reported optimum growth temperature for kikuyugrass to be near 30 ^{o}C.

g. Nutrient requirements

Kikuyugrass requires soils of moderate to high fertility levels for productive growth. In Australia, this grass has been established successfully after forest clearing but, as fertility levels drop, it is replaced by other grasses (Quinlan and Shaw, 1975). Growth of kikuyugrass is restricted at pH below 4.4 (Awad et al., 1976). Russell (1976) classified it as one of the most salt tolerant among ten tropical grasses in his study.
P. clandestinum extracts soil moisture efficiently and is able to persist during dry periods (Mears, 1970).

Response to fertilizer application has been well documented in Hawaii. Application of 224 kg ha^{-1} $year^{-1}$ (200 lbs A^{-1} $year^{-1}$) of N and P produced 12,320 and 9,296 kg DM ha^{-1} $year^{-1}$ (11,000 and 8,300 lbs DM A^{-1}) respectively as compared to 4,816 kg DM ha^{-1} $year^{-1}$ (4,300 lbs DM A^{-1}) for the control (Tamimi, 1971a). Several-fold increases in dry matter production occurred when N applied was increased from 117 to 874 kg ha^{-1} (Whitney, 1974a) and from 22 to 168 kg ha^{-1} (Whitney, 1974b). Tamimi (1971b) monitored the response to levels of up to 1,120 kg ha^{-1} (1,000 lbs A^{-1}) of N, P and K on a Typic Dystrandept soil. Highest DM production was observed at 840 kg ha^{-1} (750 lbs A^{-1}) where kikuyugrass yielded close to 22,624 kg ha^{-1} $year^{-1}$ (20,200 lbs A^{-1} $year^{-1}$). Application rates of 1,120 kg N ha^{-1} (1,000 lbs N A^{-1}) was apparently conducive to an outbreak of leaf blight which reduced yield in that treatment. P response increased as higher rates of this element were applied. This response was explained by the high P fixation capacity of the soil. On a different location no difference was found between the application of 112 and 560 kg P ha^{-1} (100 and 500 lbs P A^{-1}) (Boyd, 1968). Benefit from K application was only observed at the highest K level (1,120 kg K ha^{-1}, Tamimi, 1971b). High responses to N fertilization have also been reported by Mears and Humphreys, 1974a; Colman, 1966b (as cited by Whitney, 1974a) and Humphreys, 1981. Response to P application seems to be limited to extremely deficient soils (Mears, 1970).

h. Kikuyugrass-legume associations

Kikuyugrass-legume associations were shown to produce higher yields of dry matter and crude protein (CP) than pure grass stands (Boyd, 1968; Tamimi and Matsuyama, 1975), however, producers have had much difficulty in maintaining good kikuyugrass-legume associations.

Legume disappearance has been attributed to poor nutrition and management practices, unsuitability of the legume and insect or disease attack and not to the aggressiveness of kikuyugrass (Quinlan and Shaw, 1975). In Hawaii kikuyugrass has been grown in sucessful association with white clover (Trifolium repens), big trefoil (Lotus pedunculatus) and green leaf desmodium (Desmodium intortum) (Tamimi et al., 1984). Effects of fertilizer application on the establishment of big trefoil were studied by Tamimi and Matsuyama (1975). They showed the need for P and K application for the establishment of this legume on existing kikuyugrass pastures. Boyd (1968) reported similar results when he applied P to a similar association. Legume establishment in existing kikuyugrass pastures can be aided with the application of herbicides like Dalapon and Diazinon (Tamimi et al., 1984).

Addition of N fertilizer decreased the legume proportion of kikuyugrass pastures (Tamimi and Matsuyama, 1975; Mears and Humphreys, 1974a). This may probably be the reason for the low legume component of the pasture made up by Trifolium repens and Trifolium incarnatum reported by Tamimi et al. (1968). Grazing management affects legume persistency. High stocking rates have increased the proportion of white clover in continuous grazing (Mears and Humphreys, 1974a).

Tropical legumes such as Neonotonia wightii (Glycine javanica) have also been associated with kikuyugrass (Holder, 1967). Tropical legumes may require a different management strategy since they are more severely affected by defoliation. Infrequent grazings are necessary to maintain tropical legumes even though this has a detrimental effect on the grass quality (Mears, 1970). Rotational grazing has been advocated to manage not only tropical but also temperate legumes associated with kikuyugrass (Quinlan and Shaw, 1975).

i. Nutritional quality and animal performance

Nutritional quality of kikuyugrass decreases with increasing length of regrowth. Sherrod and Ishizaki (1967) reported a decrease in in vivo organic matter digestibility from 60.0% at three weeks to 45.2% at 24 week regrowth. Crude protein decreased from 20.8 to 4.9% during this same period while CP digestibility went from 71.2 to 20.4%. Digestible energy levels were less affected particularly with stages of regrowth of up to 12 weeks.

Crude protein in young regrowth of fertilized pastures is generally high (18% or more). In the study conducted by Holder (1967), CP level did not fall below 12% after 99 days of regrowth except for winter carry over forage. High CP values for young regrowth were reported by Colman and Kaiser (1974). Other authors reported lower CP contents in grazed pastures ranging from 7.9-9.2% (Tamimi et al., 1968), 10.5-14.4% (Campbell et al., 1971) and 7.2-12.2% (Mears and Humphreys, 1974a).

Tamimi et al. (1968) reported increased protein levels with application of 56 kg N ha^{-1} (50 lbs A^{-1}). Further increases in N rates resulted in reductions of CP which were attributed to the more vigorous growth with increased N supply. Other experiments have shown CP increases in kikuyugrass only after a minimum of 224 kg N ha^{-1} (200 lbs N A^{-1})(Tamimi, 1971a; Campbell and Ho-a, 1971) were applied. In Australia, N content of whole tops was not affected by N fertilization over the range of 0-336 kg ha^{-1} (Mears and Humphreys, 1974a); while in the Kohala region of the Island of Hawaii application of 84 kg N ha^{-1} increased the CP of kikuyugrass (Campbell et al., 1971). These apparent discrepancies may be related to differences in N status of the soils. In general, the high levels of crude protein found in kikuyugrass suggest that in most situations animal production would not be limited by protein intake. Other mineral requirements by cattle can be met by fertilized kikuyugrass with the possible exception of Ca (Mears, 1970) and Na (Mears and Humphreys, 1974b).

Deficiency of digestible energy is the major factor limiting milk (Holder, 1967; Colman and Kaiser, 1974) and beef (Mears and Humphreys, 1974b) production from kikuyugrass pastures. Minson (1972) compared digestibility and dry matter intake of five tropical grasses cut at monthly intervals and with six different periods of regrowth from 28 to 105 days. The grasses (*Setaria splendida*, *Digitaria decumbens*, *Chloris gayana*, *Panicum maximum* and *Pennisetum clandestinum*) were dried and fed to penned sheep. Dry matter digestibility (DMD) of monthly regrowths of kikuyugrass was the lowest observed (60% DMD). Differences among grasses was only of the magnitude of 5.1 per cent units. *P. clandestinum* and *P. maximum* had the lowest DMD values for the mature regrowth series. Intakes of *P. clandestinum* were also the lowest ones although with the mature regrowth they were similar to those of *C. gayana*, *P. maximum*, and *S. splendida*. Depression in intake caused by increasing plant maturity was less with *P. clandestinum* and *D. decumbens*. Even though Sherrod and Ishizaki (1967) did not compare the intake of *P. clandestinum* with that of *D. decumbens*, their results show higher digestibilities and intakes for D. decumbens. Values for digestible organic matter reported by these researchers at three and twelve weeks regrowth were 60.6-56.0% and 69.4-71.0% for P. clandestinum and D. decumbens respectively. Similar results were published by Campbell and Ho-a (1971).

Increased animal productivity from kikuyugrass pastures in Hawaii were obtained with N and N-P-K fertilizer applications (Campbell et al., 1971; Campbell et al., 1977; Tamimi et al., 1968). Increases in beef production were attributed to increases in forage yield rather than increases in liveweight gain per animal (Tamimi et al., 1968; Campbell et al., 1971). Similar results have been reported from Australia (Mears and Humphreys, 1974b). Introduction of a legume component in kikuyugrass pastures can increase animal output.

Animal performance from unfertilized kikuyugrass pastures was evaluated on a put-and-take trial against treatments of N-application (129 kg N ha^{-1} $year^{-1}$) and associations with greenleaf desmodium, big trefoil and New Zealand white clover (Tamimi et al., 1984). After 2.8 years of grazing on a three-week in and six-weeks out rotational system, dry matter production was highest in the N-fertilized treatment followed by the greenleaf desmodium, New Zealand white clover and big trefoil mixtures. Dry matter produced in the control treatment was less than half of that in the other plots. Crude Protein levels of the grass-legume associations were higher than those of pure kikuyugrass stands. Animal productivity in the kikuyugrass-legume mixtures was 672 kg ha^{-1} $year^{-1}$ (600 lbs A^{-1} $year^{-1}$) or more while the fertilized and unfertilized pastures produced 638 and 370 kg ha^{-1} $year^{-1}$ (570 and 330 lbs A^{-1} $year^{-1}$) respectively. New Zealand white clover was the only legume which did not persist under the grazing method utilized (Tamimi et al., 1984). Data from Hawaii support the claim that where kikuyugrass is grown with legumes intake is not a problem.

The highest animal productivity per acre on an unfertilized kikuyugrass pasture in Hawaii has been 812 kg ha^{-1} (725 lbs A^{-1}). This level of productivity was obtained on a commercial ranch utilizing intensive grazing management (Leung and Smith, 1984).

III. MATERIALS AND METHODS

1. Site description

The experiment was conducted at the Mealani Experiment Station on the island of Hawaii. This station is located at 853 m (2800 feet) above sea level. Average annual precipitation is 1422 mm (56 in) and average maximum and minimum temperatures are 21 and 13 ^{o}C (69.9 and 55.4 F) (Reimer et al., 1987). Paddocks used had slopes from 0-3% and soils were classified as Hydric Dystrandepts (Ikawa et al., 1985). Initial botanical composition of the pasture was: kikuyugrass (88.6%), pangolagrass (7.3%), white clover (3.2%) and weeds (0.9%).

2. Trial A

a. Treatments and animal management

Trial A was carried from out from June 10 through August 9, 1987,. Fifteen Holstein steers with an average initial weight of 156 kg were randomly allotted into three groups. Daily pasture allowances (kg DM animal^{-1} day^{-1}) was equal for all groups. However, one group was shifted twice daily (6:30 a.m. and 2:00 p.m.), another group was shifted once daily (6:30 a.m.) and the third group was shifted every three days (6:30 a.m.). Shifting times were selected to approximately coincide with natural grazing activity (Kilgour and Dalton, 1984). Pasture allowances were not constant throughout the trials, but the changes made were equal for all groups.

To improve the welfare of animals shifted once or twice daily, these animals were allowed access to the area given in a particular day as well as the area allocated the day before. In this manner, they had a larger area to walk and/or rest. Since the material from the previous day's grazing was made up mostly of stolons and litter previously trampled and/or soiled by animals, this practice should not have affected the treatments imposed. Animals shifted every three days had access to larger areas than animals from the other two treatments and were not allowed access to previously grazed areas.

Portable electric fences were used to provide the steers with appropriate allocations (Fig. 1). Portable metal water troughs, supplied by plastic hoses, were used in all paddocks. All animals had access to a complete mineral supplement (Table 1). Steers were weighed initially and approximately every 21 days thereafter to monitor liveweight gain (LWG). Weighing periods were used to spray for fly control and treat sick animals. Repeated measures analyses (Winer, 1971) were conducted on LWG data treating initial weight as a covariate.

b. Pre- and post-grazing dry matter determination

Two different methods were used to estimate pre-grazing forage dry matter for the once and twice daily shifting groups. During the first 21 days of the trial, ten green forage height measurements were taken in the areas to be allocated the following day. Average height was related to green forage dry matter per hectare by using results from Smith (Appendix A). For the remainder of the trial pre-grazing and post-grazing pasture dry matter determinations were made by selecting two adjacent quadrats of 0.25 m^2 with average pasture height. One

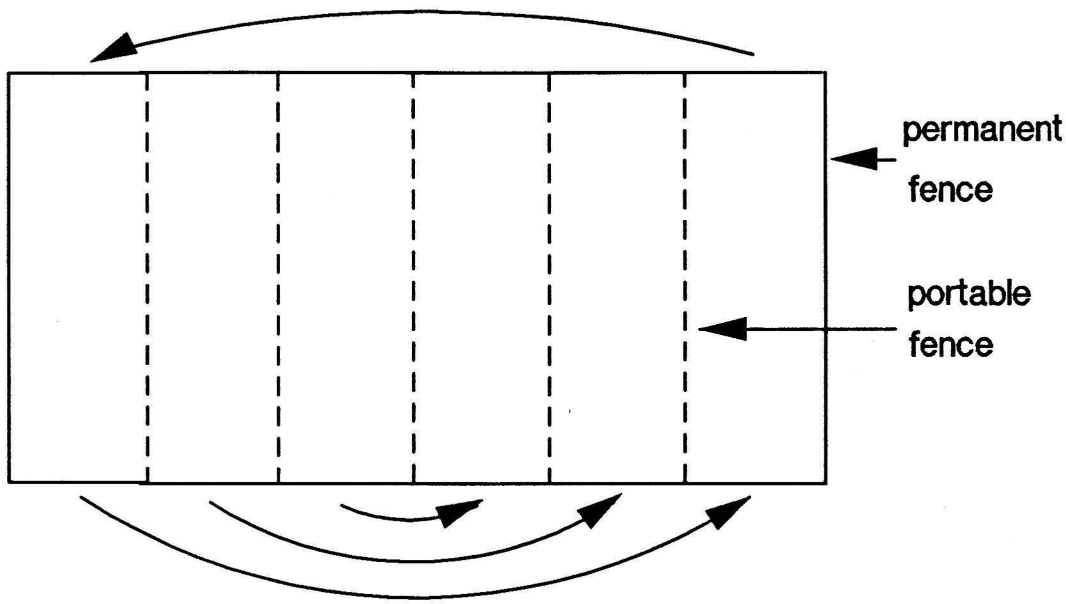


Figure 1. Field layout and animal movement.

Table 1. Analysis of mineral supplement used in Trial A.

Guaranteed analysis	— g kg^{-1} —
Crude protein, not less than	25
Calcium (Ca), not less than	80
Calcium (Ca), not more than	95
Phosphorus (P), not less than	85
Salt (NaCl), not less than	250
Copper (Cu), not less than	10
Iron (Fe), not less than	1
Magnesium (Mg), not less than	30
Zinc (Zn), not less than	5
Manganese (Mn), not less than	1
Iodine (I), not less than	0.1
Cobalt (Co), not less than	0.02
Selenium (Se), not less than	0.018

quadrat was clipped before grazing; the other was clipped after grazing. Differences between the two provided an estimate of forage intake. Pasture was clipped by the same operator at 2.5 cm stubble height (visually estimated) using electric shears; and samples were dried in an oven at 60 ^{o}C. A 2.5 cm stubble height was selected because animals grazing kikuyugrass seldom graze below this height (Smith, personal communication). Forage dry matter was estimated on a per hectare basis and used to make the allocations. Dry matter was estimated and allocations were determined three days before the animals would graze a particular area. These same methods were used to determine pre-grazing and post-grazing pasture dry matter in the three day shifting group. However, two or three quadrats were clipped as the area to be allocated was larger than for the other two groups.

c. Pasture height and capacitance meter

Other measurements were taken on the quadrats clipped before grazing in Trial A in an effort to obtain an easier method of estimating pasture dry matter. Total plant height was estimated on 51 quadrats by taking the average of 5 measurements per quadrat while a capacitance meter was used in 68 quadrats. The capacitance meter model and method of use were described by Vickery et al. (1980). Air capacitance above the pasture was measured for each quadrat and subtracted from the average of five meter readings. Plant height and capacitance meter reading were later related to pasture yield above 2.5 cm stubble height.

d. Pasture fertilization and quality

Six weeks before the trial started, the pasture was heavily grazed to reduce the sward to a uniform height; the pasture was then fertilized with 126 kg N, 13 kg P and 25 kg K per hectare. Hand-picked pluck-samples of approximately 400 gm fresh weight were collected from the forage allocated to each group every three days. These samples were oven dried at 40 ^{o}C for 48 hours and ground through a 1 mm sieve mill for analyses. In vitro digestibilities were determined by the technique described by Goering and Van Soest (1970). Nutrient analyses were conducted using the standard procedures of the Diagnostic Service Center, Hawaii Institute of Tropical Agriculture, University of Hawaii.

3. TRIAL B

a. Treatments and animal management

Trial B was conducted from January 7 through March 14, 1988,. The same shifting treatments were applied to a new group of 24 Holstein steers with an average initial weight of 151 kg. This trial was conducted in much the same way as the 1987 trial. Steers shifted once daily were only able to graze on the area allocated on any particular day. The backfence of the group shifted twice daily was moved once the afternoon allocation was given. Mineral supplement used in this trial was different from that in trial A (Table 2).

b. Pre- and post-grazing dry matter determination

Pre-grazing dry matter was estimated by taking 4 clippings from 0.25 m^2 quadrats placed randomly in an area estimated to provide forage

Table 2. Analysis of mineral supplement used in Trial B.

Guaranteed analysis	— $g\ kg^{-1}$ —
Crude protein, not less than	35
Crude fat, not less than	5
Crude fiber, not more than	50
Ash, not more than	250
Calcium (Ca), not less than	85
Phosphorus (P), not less than	78
Magnesium (Mg), not less than	30
Manganese (Mn), not less than	0.8
Copper (Cu), not less than	10
Iodine (I), not less than	0.1
Salt (NaCl), not less than	210
Salt (NaCl), not more than	250

for three days. Post-grazing pasture mass was determined every day in the groups shifted once and twice daily by clipping a randomly selected quadrat. Two or three quadrats were clipped in the area grazed by the group shifted every three days.

c. Pasture fertilization and quality

This trial included a second pasture (B), similar in botanical composition to the previous one (A). Pasture A was fertilized with 116 kg N ha^{-1} a week before grazing was initiated, while pasture B received 69 kg N, 30 kg P and 57 kg K per hectare one month before its use. Pasture B was grazed four weeks prior to this trial while pasture A was six weeks old when put in use in this trial. Pluck samples were taken as in Trial A.

IV. RESULTS AND DISCUSSION

1. <u>Capacitance meter and kikuyugrass height</u>

a. Capacitance meter

The relationship between capacitance meter readings and kikuyugrass yields was non significant (r=0.41) (Fig. 2). These results differed from those reported by Michell and Large (1983), Roberts et al. (1984) and Vickery et al. (1980), where the capacitance meter determined the yield of several subtropical and temperate species with an accuracy better than 82.8%.

Free moisture present in the forage affected the readings from the capacitance meter (Vickery and Nicol, 1982 as cited by Roberts et al. 1984). Presence of large amounts of free moisture on kikuyugrass forage in my study rendered the capacitance meter ineffective. At Mealani Experiment Station free moisture collects on plants from precipitation and/or fog drip. There is evidence that the capacitance meter cannot give accurate results on swards with large amounts of senescent material (Michell and Large, 1983). Although the proportion of senescent material was not measured in this study, considerable amounts of senescent material were observed within the kikuyugrass mat. Mears and Humphreys (1974a) reported amounts of litter in kikuyugrass swards ranging from 1,655 to 5,030 kg ha^{-1}. The capacitance meter could provide better results in situations where kikuyugrass forage is dry and the mat is under control. Determination of botanical composition in future studies should clarify the influence of kikuyugrass litter on capacitance meter readings.

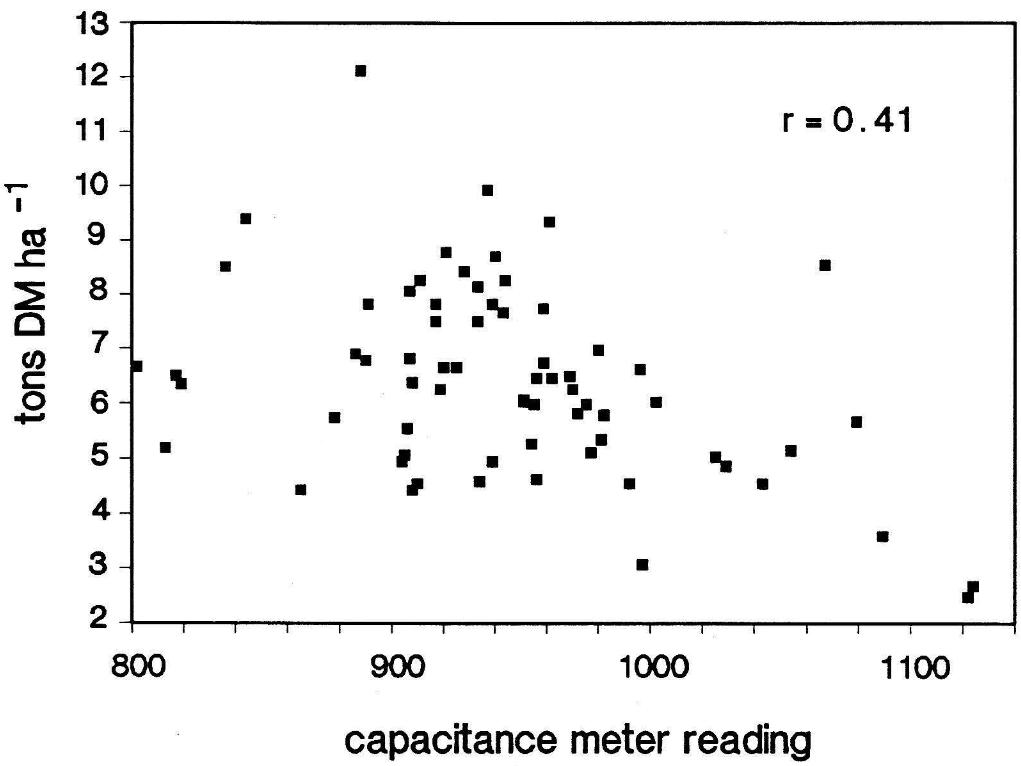


Figure 2. Relationship between capacitance meter reading and yield of kikuyugrass (tons DM ha^{-1}).

Michell and Large (1983) obtained good estimates of perennial ryegrass yields by clipping at 18 mm stubble height. By utilizing a 'sled' on their cutting device they ensured cutting at a constant height. This approach should be considered in future studies.

b. Kikuyugrass height

From the linear, logarithmic and quadratic models used, the quadratic model provided the best fit (r^2=0.64) between kikuyugrass height and yield per hectare above 2.5 cm (Fig. 3). Whitney (1978b) found that height alone accounted for only 56% of the variation in yield. Since the influence of the kikuyugrass mat was minimized in these experiments it appears that wide variations in tiller dry matter and density make height a poor indicator of kikuyugrass yield. For certain temperate species pasture height can be used to estimate grazable dry matter with 88% accuracy (Piggot, 1986).

Plant height could provide better estimates of kikuyugrass yield in pastures where the mat is under control. By minimizing the amount of stolons in the sward it may be possible to obtain a better relationship between height of the resulting leafier sward and yield.

2. Pasture quality

In vitro digestible dry matter (IVDDM) and CP values of pluck samp les did not differ significantly among treatments in any of the trials (Tables 3 and 4). No significant relationships were found

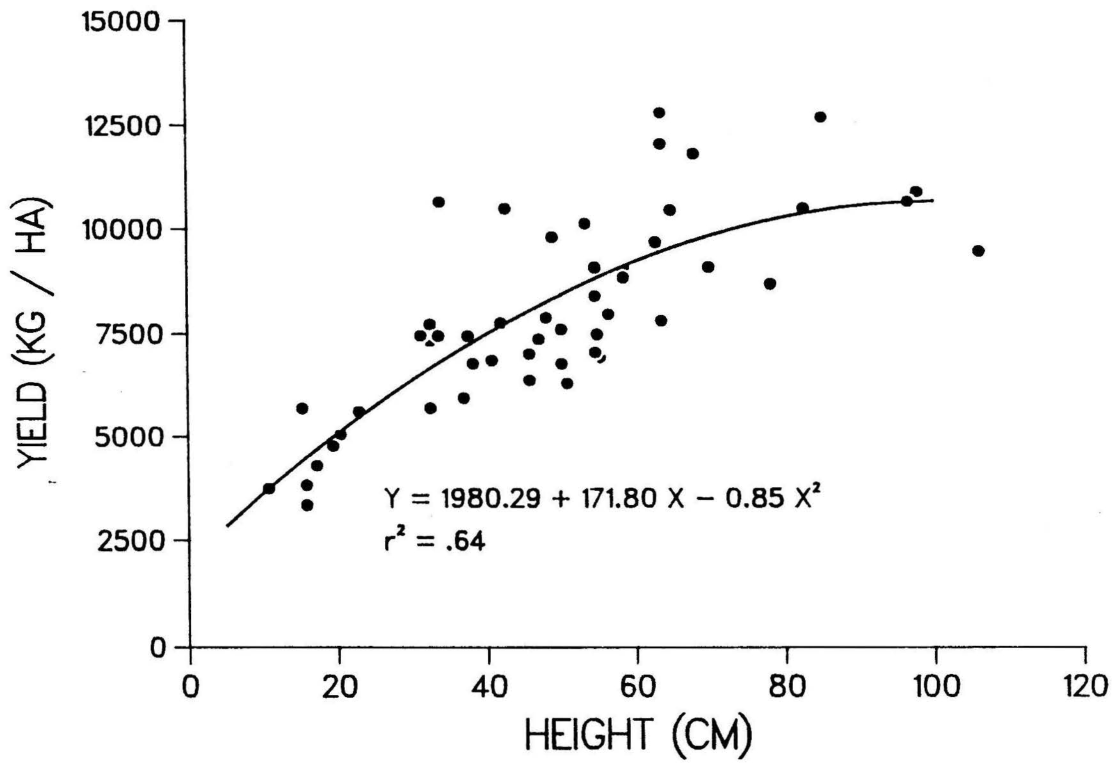


Figure 3. Relationship between plant height (cm) and yield (kg/ha) of kikuyugrass.

Table 3. Mean *in vitro* digestible dry matter (IVDDM) and crude protein (CP) of kikuyugrass for the three shifting frequencies during each weighing interval. Trial A.

Shifting frequency	Weighing interval 1		2		3	
	IVDDM	CP	IVDDM	CP	IVDDM	CP
	$g\ kg^{-1}$					
Twice daily	609	170	736	168	769	159
Once daily	614	201	739	172	768	154
Three day	681	179	732	179	778	175

Table 4. Mean *in vitro* digestible dry matter (IVDDM) and crude protein (CP) of kikuyugrass for the three shifting frequencies during each weighing interval. Trial B.

Shifting frequency	Weighing interval 1		2		3	
	IVDDM	CP	IVDDM	CP	IVDDM	CP
	$g\ kg^{-1}$					
Twice daily	773	227	758	169	813	195
Once daily	810	236	812	167	752	184
Three day	802	232	810	161	679	191

between IVDDM and N, P, K, Ca or Mg concentrations of kikuyugrass (Table 5).

Field observations indicated that pluck samples could not be considered representative of the diet selected by the animals because they did not include stoloniferous material in the proportion eaten by the steers. Due to difficulty in taking representative pluck samples from kikuyugrass swards, it appears that more reliable estimates of the quality of the forage ingested can be obtained with the use of esophago-fistulated animals.

In vitro dry matter digestibility and CP values obtained from the pluck samples in both of these trials were higher than those reported by Sherrod and Ishizaki (1967) and Campbell and Ho-a (1971). These differences are not surprising since those authors harvested plants at approximately 5 cm stubble height as compared to plant tops collected from plucking in these trials. Values from trial B are comparable to those reported by Carpenter et al. (1987). The higher IVDDM and CP values obtained in trial B were attributed to the lack of any well developed mat in pasture B. Pasture A had a well developed mat which influenced sample measurements.

Tables 6 through 9 present the concentrations of P, K, Ca, Mg and Na in the pluck samples. Similar concentrations of P, Ca and Mg for kikuyugrass were reported by other authors (Campbell et al., 1971; Sherrod and Ishizaki, 1967 and Campbell and Ho-a, 1971). In contrast, the K values from this experiment were higher than those reported by Campbell et al. (1971) and Sherrod and Ishizaki (1967). Copper values

Table 5. Simple coefficients of determination for _in vitro_ digestible dry matter (IVDDM) with N, P, K, Ca and Mg concentrations in plant tops of kikuyugrass.

IVDDM and:	df	r^2	
N	115	0.05	n.s.
P	115	0.005	n.s.
K	115	0.03	n.s.
Ca	115	0.11	n.s.
Mg	115	0.06	n.s.

n.s.= nonsignificant

Table 6. Mean phosphorus, potassium, calcium, magnesium and sodium concentrations of kikuyugrass samples during each weighing period. Trial A.

Weighing period	P	K	Ca	Mg	Na
	$g\ kg^{-1}$				
1	2.5	34.4	2.8	2.8	0.7
2	2.3	36.9	2.7	2.7	0.6
3	2.2	34.6	2.7	2.7	1.1

Table 7. Mean manganese, iron, copper and zinc concentrations of kikuyugrass samples during each weighing period. Trial A.

Weighing period	Mn	Fe	Cu	Zn
	$mg\ kg^{-1}$			
1	57	108	9	28
2	57	119	9	27
3	102	127	9	29

Table 8. Mean phosphorus, potassium, calcium, magnesium and sodium concentrations in pluck samples taken from kikuyugrass pastures during each weighing period. Trial B.

Weighing period	P	K	Ca	Mg	Na
			$g\ kg^{-1}$		
1	3.0	35.7	3.7	3.5	1.0
2	2.3	30.2	3.6	3.3	0.9
3	3.3	30.5	3.8	3.6	1.1

Table 9. Mean manganese, iron, copper and zinc concentrations of kikuyugrass samples during each weighing period. Trial B.

Weighing period	Mn	Fe	Cu	Zn
		mg kg-1		
1	95	281	18	44
2	61	155	11	32
3	49	105	13	31

from this experiment were lower than those reported by Campbell et al. (1971).

Nutrient analyses indicated that Ca concentration in kikuyugrass was only high enough to maintain a liveweight gain of approximately 0.23 kg animal^{-1} day^{-1}. Phosphorus concentration in the grass was also insufficient at times to maintain the gains observed (NRC, 1984). All other nutrients analyzed with the possible exception of copper were present in adequate amounts. Copper levels during trial A were marginal to meet the recommended 10 mg kg^{-1} (10 ppm) concentration in the diet (McDowell et al., 1983).

3. Pasture allocation

Amounts of DM available (pre- and post-grazing) for each treatment are presented in tables 10 and 11. There were no statistically significant differences among treatments in any of the trials.

Pre-grazing dry matter values reported for the first weighing period in trial A showed the inaccuracy of the pasture height technique used to estimate kikuyugrass yield. Animals achieved liveweight gains which would have required a dry matter intake of 3.8 kg DM animal^{-1} day^{-1} (NRC, 1984). The pasture height technique underestimated the amount of dry matter offered.

In contrast to reports from strip grazing studies (Minson et al, 1976), differences between pre and post-grazing dry matter measurements underestimated forage intake in these trials. This is attributed to the cutting height used and the effect of grazing on the pastures. Visual observation of pastures and steer grazing suggested that intake of

Table 10. Mean pre- and post-grazing dry matter yields for each of the shifting frequency treatments and weighing periods. Trial A.

Shifting frequency	Weighing period 1 Pre	1 Post	2 Pre	2 Post	3 Pre	3 Post
	kg animal-1 day-1					
Twice daily	2.8	-	5.8	2.8	8.4	3.0
Once daily	3.1	-	5.7	3.2	6.9	3.8
Three day	3.0	-	5.6	3.8	6.8	3.5

Table 11. Mean pre- and post-grazing dry matter yields for each of the shifting frequency treatments and weighing periods. Trial B.

Shifting frequency	Weighing period 1 Pre	1 Post	2 Pre	2 Post	3 Pre	3 Post
	kg animal-1 day-1					
Twice daily	8.3	5.7	8.4	6.5	6.7	4.4
Once daily	8.7	5.3	8.4	7.2	6.7	4.8
Three day	8.4	3.8	8.4	6.7	6.7	4.9

stoloniferous material was high during both trials. Much of this stoloniferous material was not included in pre grazing dry matter values because a large amount of it was below the 2.5 cm cutting height. During grazing, steers pulled stolons from ground level to heights above 2.5 cm. These stolons were clipped as part of the post grazing forage thus inflating these values. The use of external markers such as chromic oxide (Cr_2O_3) to estimate fecal production (Minson et al, 1976) should be considered for future estimates of kikuyugrass intake by grazing animals.

4. Liveweight gain

a. Trial A:

Symptoms of Infectious Bovine Rhinitracheitis (IBR) were seen in the steers. Treatment with liquamycin (LA 200^R) was followed when these symptoms were severe. After 44 days one animal was removed from each treatment due to poor health. Two days later one of these animals died. The autopsy revealed that the animal died from respiratory complications due to a severe worm infestation which aggravated the viral infection. Statistical analyses were performed on data from the four steers remaining on each treatment.

No significant differences in ADG were observed among treatments. Fig. 4 shows the liveweight gains obtained during trial A. Animals appeared to have higher liveweight gains with higher shifting frequencies; however, after 44 days, animal health deteriorated rapidly and the trend dissapeared. Weight losses which took place after 27 days were due to the worm infestation. Although the animals were dewormed

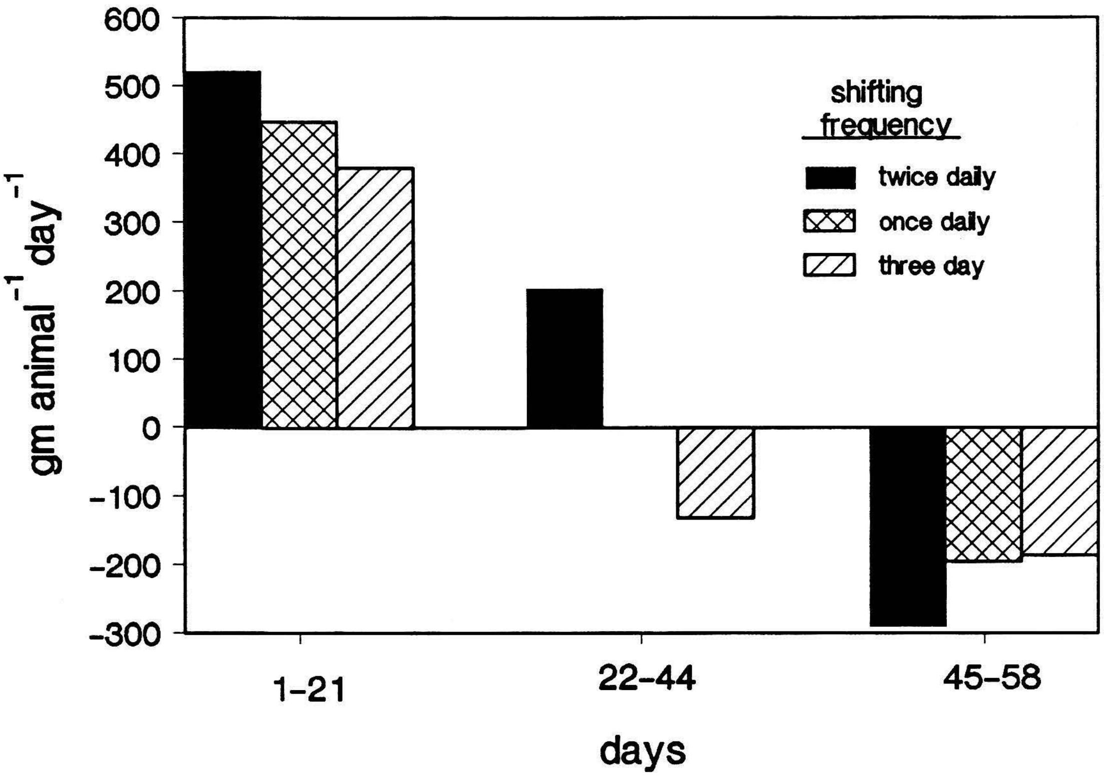


Figure 4. Average daily gain (gm animal^{-1} day^{-1}) of Holstein steers grazing kikuyugrass under three shifting frequencies. Trial A.

with fenbendazole (Safe-guard^R) after the second weighing, there was not enough time for the animals to show any recovery before the last weighing at 58 days. Animal health problems contributed to very high coefficients of variation during this trial (Table 12).

b. Trial B:

In order to avoid the health problems encountered in 1987, the steers used in this trial were dewormed one week before the trial started and again after 27 and 48 days. Symptoms of IBR were observed; however, animal health was much better in trial B than in trial A. Coefficients of variation for each weighing period in trial B were lower than those observed in trial A (Table. 13). Differences in rumen fill are the largest source of variation in liveweight. Two of the techniques that have been proposed to minimize differences in rumen fill include fasting of animals for approximately 12 hours before weighing and weighing animals always at the same hour (Mannetje et al.,1976). One of these techniques should be used in future experiments in order to reduce variation in ADG.

Average daily gains recorded were not significantly different (Fig. 5). Ample supplies of kikuyugrass were allocated to steers until the first weighing period at 27 days. During this period the animals shifted every three days had an ADG of approximately 250 gm higher than that of the other two treatments. Since there were no replications it is not known if this was a random occurrence or if this was a treatment effect. Following the first weighing period the amount of forage allocated was reduced. As a result, ADG decreased and the groups

Table 12. Coefficients of variation (CV) for average daily gain during each weighing period. Trial A.

weighing period	CV
	(%)
1	45
2	1162
3	137

Table 13. Coefficients of variation (CV) for average daily gain during each weighing period. Trial B.

weighing period	CV
	(%)
1	20
2	41
3	32

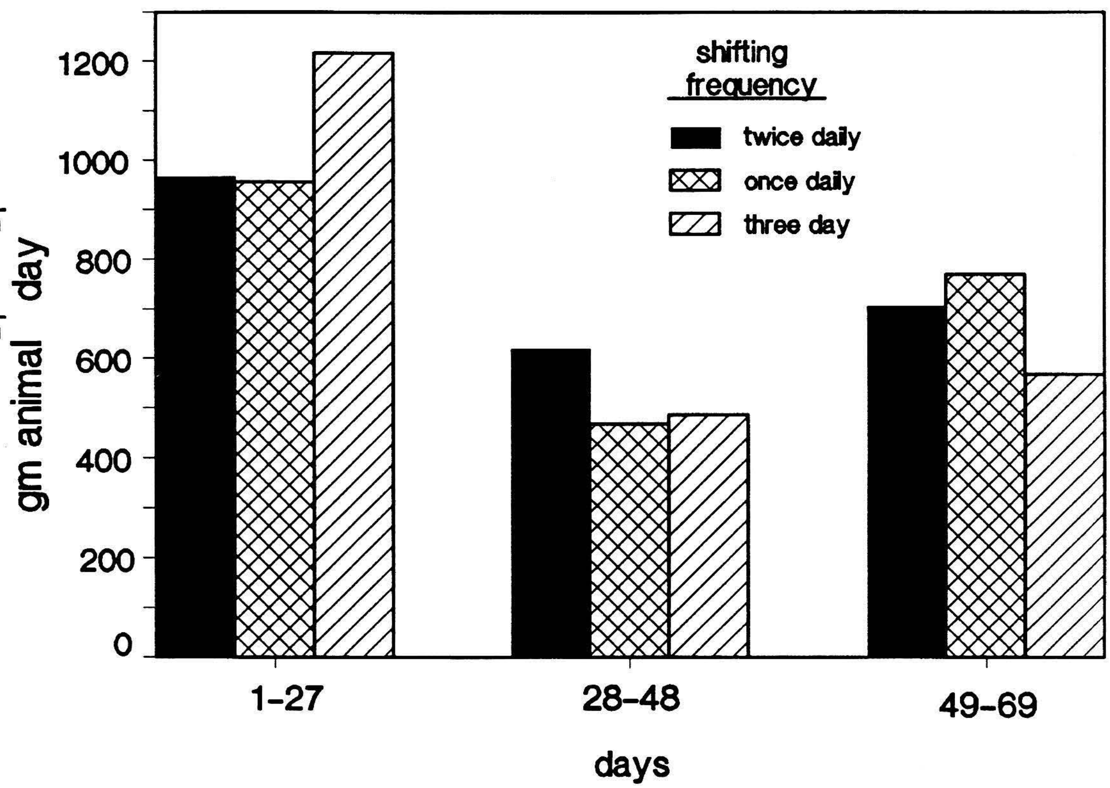


Figure 5. Average daily gain (gm animal^{-1} day^{-1}) of Holstein steers grazing kikuyugrass under three shifting frequencies. Trial B.

shifted once and twice a day showed a tendency to perform better than the three-day group.

Mears and Humphreys (1974b) indicated that even at low stocking rates ADG on kikuyugrass pastures ranged from 0.19 to 0.64 kg animal^{-1} day^{-1} when no mineral supplement was offered. Gains of 1 kg animal^{-1} day^{-1} obtained during the first weighing period in Trial B compare well against the 295-454 gm animal^{-1} day^{-1} (0.64-1.0 lbs animal^{-1} day^{-1}) rate of gain for yearling steers grazing kikuyugrass pastures in the same geographical area (Campbell et al., 1987). These gains indicate that not only stocking rate but individual animal performance can be increased through proper management practices such as fertilization, mineral supplementation and reduction of the kikuyugrass mat. The challenge will be to continuously maintain those gains.

Although there is no evidence to suggest that frequent shiftings result in higher liveweight gains, the groups shifted more frequently showed a tendency to perform better when the amount of feed was enough to make liveweight gains below 650 gm animal^{-1} day^{-1}. This would suggest that when there is an ample supply of forage, a three day grazing interval would be appropriate but, when the supply of forage is short the level of subdivision and shifting frequency should be increased.

Field observations confirmed that animals grazed whenever they were shifted, however, whether or not frequent shiftings result in increased feeding frequencies is not known. Grazing is an energy-requiring activity and may influence the efficiency of feed utilization. In a comparison of continuous versus rotational grazing, animals under rotational grazing had a 44% lower grazing energy expenditure and higher efficiency of food conversion. Higher efficiency of food conversion was achieved due to lower energy requirements to maintain body weight (O'Sullivan, 1984). It is possible that grazing energy expenditure of animals in the higher shifting frequencies was lower than that of those animals shifted every three days. Field observations suggested that animals in the three day shifting treatment spent considerable time in the third day trying to select scarce green material present in the sward at that time. Use of vibracorders to measure grazing time (Minson et al., 1976) could clarify this hypothesis.

V. CONCLUSIONS AND RECOMMENDATIONS

-Under the conditions of this study neither the pasture capacitance meter nor the kikuyugrass height technique provided satisfactory estimates of kikuyugrass yield.

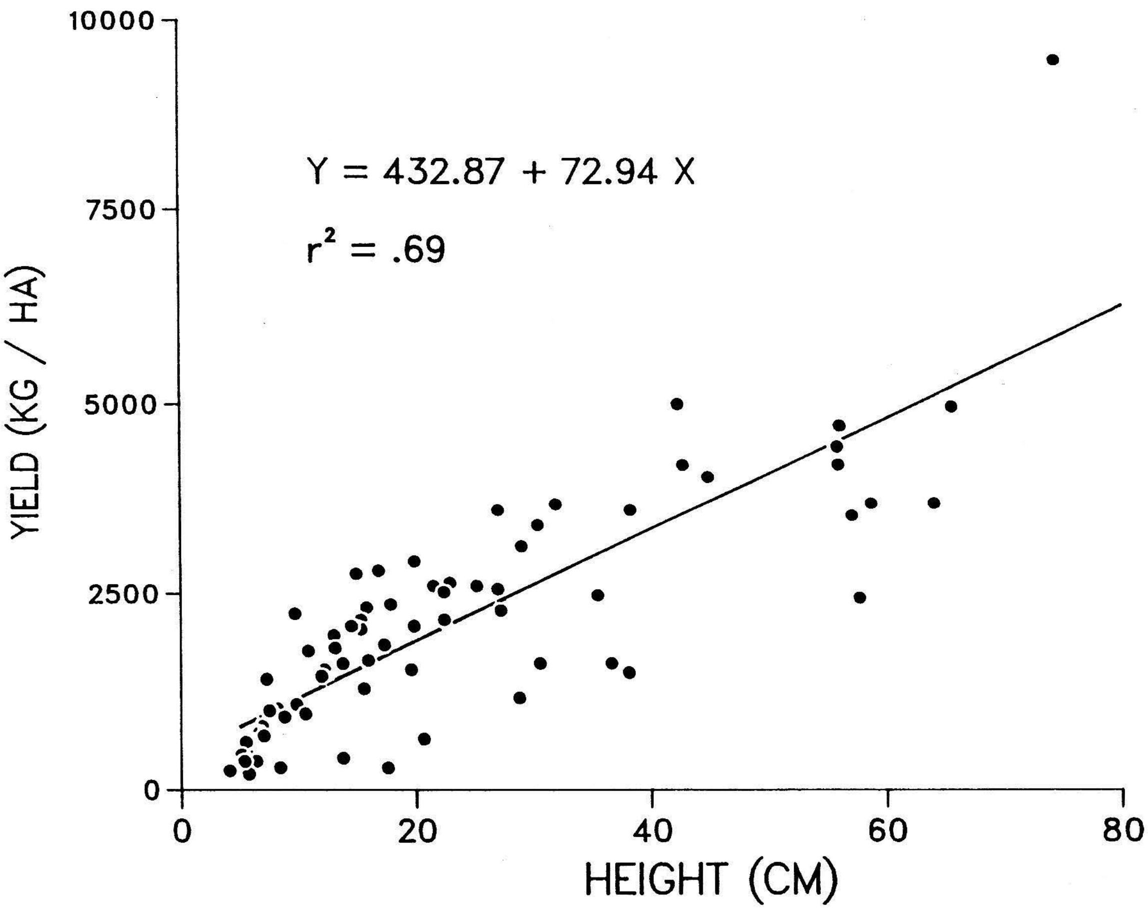
-No significant differences were observed among the shifting frequencies used, however, there was a tendency for the higher frequency treatments to perform better when ADG was below 650 gm animal^{-1} day^{-1}.

-Future experiments should include observations of animal behavior. This approach could give a clue as to the energy expenditure of animals under different shifting frequencies and equal allocations.

-Effects of shifting frequencies on pasture growth should be monitored as they can bring about large differences in favor of shorter grazing intervals (Milligan, personal communication).

-Precision of future experiments can be increased by replicating and by minimizing differences in rumen fill that can mask the treatment effects.

APPENDICES



Appendix A. Relationship between height of green forage (cm) and yield (kg/ha) of kikuyugrass. (Smith, unpublished data).

APPENDIX B. *In vitro* digestible dry matter (IVDDM) and nutrient analyses of kikuyugrass samples taken during Trial A.

tmt[a]	IVDDM	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn
	%							ppm			
A	70.08	2.66	0.24	3.17	0.30	0.31	0.04	88	105	8	34
B	54.92	3.76	0.30	3.68	0.30	0.26	0.16	90	123	11	34
C	76.58	2.98	0.30	4.14	0.30	0.26	0.04	60	216	10	29
A	44.95	2.79	0.25	4.17	0.28	0.26	0.06	93	101	9	31
B	42.68	2.83	0.26	3.83	0.25	0.24	0.13	134	106	9	31
C	53.70	3.24	0.26	4.01	0.32	0.26	0.06	30	84	9	27
A	79.60	2.96	0.27	3.91	0.26	0.23	0.03	40	90	9	27
B	65.65	4.09	0.31	3.40	0.31	0.33	0.06	48	119	9	28
C	65.73	3.48	0.28	3.94	0.31	0.25	0.03	35	86	10	27
A	57.26	3.01	0.26	3.66	0.26	0.27	0.04	41	92	11	27
B	76.40	2.99	0.27	3.52	0.25	0.28	0.04	63	104	10	29
C	73.23	2.53	0.22	3.46	0.34	0.29	0.04	38	147	10	29
A	55.12	2.50	0.19	3.16	0.25	0.25	0.04	45	87	10	24
B	55.92	2.72	0.21	1.74	0.24	0.30	0.10	51	83	10	29
C	72.68	2.60	0.23	3.82	0.27	0.27	0.05	30	76	11	27
A	58.48	2.41	0.23	2.94	0.29	0.30	0.04	36	92	7	26
B	72.91	2.91	0.24	1.72	0.28	0.34	0.24	69	143	7	26
C	66.78	2.40	0.22	3.74	0.25	0.26	0.04	33	88	8	26
A	74.89	2.33	0.19	2.85	0.25	0.25	0.04	29	118	7	24
B	70.85	2.40	0.21	2.56	0.30	0.31	0.12	54	78	7	24
C	66.89	3.36	0.27	3.97	0.27	0.29	0.05	37	103	9	29
A	62.13	2.47	0.24	3.03	0.32	0.32	0.05	57	106	9	29
B	67.18	2.43	0.23	2.55	0.29	0.37	0.08	75	89	8	35
C	63.94	2.35	0.24	3.14	0.28	0.28	0.05	61	86	8	27
A	66.24	2.46	0.20	3.17	0.30	0.26	0.06	50	100	14	22
B	58.79	2.32	0.19	1.70	0.27	0.38	0.12	64	75	9	37
C	75.20	2.61	0.21	3.53	0.28	0.26	0.04	63	158	7	22
A	76.08	2.69	0.20	3.49	0.26	0.22	0.04	63	156	9	26
B	77.81	3.14	0.26	4.56	0.29	0.24	0.04	38	-	10	25
C	76.66	2.62	0.22	3.99	0.26	0.27	0.04	71	115	9	25
A	68.05	2.44	0.20	2.98	0.27	0.30	0.04	44	95	7	22
B	72.98	2.50	0.22	3.53	0.24	0.23	0.04	38	106	8	27
C	73.38	2.92	0.25	4.03	0.28	0.25	0.04	39	83	9	28
A	81.81	3.60	0.34	5.18	0.28	0.30	0.07	30	-	12	31
B	85.81	3.75	0.29	4.92	0.24	0.29	0.07	66	-	11	34
C	85.70	3.76	0.35	6.01	0.23	0.26	0.06	28	154	10	31
A	80.23	3.26	0.26	4.98	0.30	0.29	0.05	49	-	9	25
B	79.73	2.83	0.22	4.45	0.26	0.26	0.06	57	-	-	26
C	70.51	3.18	0.24	4.69	0.28	0.25	0.05	82	-	13	28
A	79.78	2.28	0.20	3.12	0.22	0.23	0.04	108	247	11	25
B	77.81	2.65	0.21	3.53	0.28	0.27	0.06	65	171	9	25
C	73.31	2.19	0.14	2.55	0.23	0.23	0.05	104	-	9	21
A	80.38	2.05	0.20	2.34	0.24	0.18	0.50	69	158	11	37

APPENDIX B. Cont.

tmt[a]	IVDDM	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn
	%							ppm			
B	79.10	2.66	0.26	3.38	0.26	0.26	0.06	91	210	10	28
C	78.46	3.32	0.29	4.21	0.32	0.30	0.07	76	156	12	36
A	79.84	2.63	0.23	3.71	0.32	0.28	0.21	64	125	11	30
B	74.91	2.74	0.22	3.87	0.28	0.33	0.04	84	149	11	33
C	80.89	2.70	0.21	3.48	0.26	0.27	0.18	161	120	9	28
A	81.33	2.60	0.21	4.43	0.27	0.28	0.04	71	102	11	32
B	75.58	2.20	0.19	2.67	0.28	0.28	0.04	169	104	8	27
C	76.99	2.33	0.20	3.16	0.30	0.30	0.04	159	120	9	25
A	75.12	2.93	0.20	3.75	0.28	0.26	0.05	62	116	9	25
B	77.98	2.69	0.22	3.93	0.26	0.26	0.05	60	107	4	26
C	73.91	2.52	0.19	3.38	0.24	0.26	0.18	217	102	9	27
A	67.83	2.52	0.21	3.26	0.26	0.28	0.06	47	95	9	26
B	76.54	2.00	0.19	3.32	0.27	0.24	0.04	89	103	8	24
C	78.93	3.10	0.24	3.02	0.30	0.34	0.11	113	143	11	26

a. tmt A = twice daily B = once daily C = three day

APPENDIX C. *In vitro* digestible dry matter (IVDDM) and nutrient analyses of kikuyugrass samples taken during Trial B.

tmt[a]	IVDDM	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn
	%							ppm			
A	82.68	3.80	0.26	3.70	0.32	0.30	0.06	59	235	16	37
B	79.64	3.72	0.30	3.64	0.35	0.32	0.08	70	580	16	43
C	79.09	3.81	0.32	3.48	0.43	0.44	0.12	86	330	15	49
A	81.64	3.99	0.38	3.76	0.27	0.27	0.10	143	402	16	44
B	83.61	4.08	0.38	4.32	0.38	0.37	0.08	147	486	17	47
C	81.09	4.12	0.35	3.98	0.46	0.41	0.08	115	343	20	48
A	81.50	4.07	0.40	3.76	0.42	0.41	0.10	120	182	19	48
B	85.16	3.92	0.36	4.08	0.42	0.42	0.08	107	202	19	46
C	87.78	4.04	0.41	4.50	0.39	0.34	0.08	108	263	23	52
A	84.11	3.97	0.36	4.52	0.42	0.37	0.08	120	170	19	39
B	83.33	4.19	0.33	4.30	0.34	0.32	0.10	127	125	16	40
C	80.79	4.14	0.32	3.68	0.38	0.34	0.10	86	124	14	39
A	84.48	3.91	0.29	3.38	0.35	0.34	0.12	126	124	14	36
B	83.56	4.08	0.31	3.76	0.43	0.39	0.10	139	193	16	36
C	82.46	3.67	0.26	3.22	0.38	0.38	0.12	64	161	15	34
A	66.51	2.70	0.19	2.66	0.33	0.34	0.18	61	405	25	80
B	72.43	2.89	0.19	2.78	0.33	0.38	0.20	76	594	20	46
C	77.72	3.16	0.23	3.14	0.36	0.35	0.28	64	312	29	49
A	60.07	2.95	0.20	2.96	0.32	0.31	0.08	57	262	15	37
B	78.92	3.51	0.20	2.06	0.33	0.34	0.10	63	272	13	38
C	72.64	3.07	0.23	3.40	0.31	0.33	0.08	50	142	14	36
A	76.04	3.20	0.23	3.14	0.34	0.35	0.06	59	132	13	34
B	81.91	2.72	0.21	3.46	0.32	0.31	0.06	55	168	13	33
C	82.23	3.01	0.23	3.26	0.38	0.36	0.06	66	106	11	32
A	77.14	1.91	0.22	2.54	0.38	0.30	0.22	95	252	14	47
B	78.82	2.29	0.20	2.98	0.34	0.31	0.10	70	147	9	39
C	78.20	2.40	0.18	2.84	0.33	0.31	0.22	69	182	16	37
A	80.26	2.58	0.18	2.92	0.33	0.32	0.06	63	142	9	34
B	79.65	2.80	0.20	3.04	0.39	0.35	0.06	50	207	10	32
C	76.90	2.61	0.20	2.98	0.37	0.32	0.20	65	313	17	43
A	83.57	2.90	0.21	3.98	0.34	0.31	0.06	74	230	11	34
B	85.12	3.27	0.21	3.56	0.34	0.33	0.06	58	129	13	32
C	83.31	2.98	0.19	2.98	0.33	0.30	0.06	55	122	11	31
A	82.15	2.73	0.24	2.80	0.32	0.32	0.08	48	125	9	26
B	82.44	2.55	0.24	3.10	0.35	0.32	0.10	45	135	10	30
C	81.08	2.46	0.25	2.80	0.36	0.32	0.08	65	130	10	28
A	49.66	2.94	0.26	3.20	0.35	0.32	0.08	58	125	12	26
B	82.39	2.84	0.25	3.20	0.38	0.32	0.08	60	125	12	27
C	83.47	2.16	0.25	2.50	0.40	0.35	0.10	55	175	12	26
A	81.53	2.68	0.27	3.10	0.40	0.32	0.07	45	110	12	28
B	77.87	2.20	0.27	2.20	0.40	0.42	0.07	55	105	9	30
C	81.64	2.39	0.26	2.70	0.35	0.35	0.08	65	105	11	30
A	76.98	2.32	0.30	1.70	0.42	0.45	0.06	40	140	10	32

APPENDIX C. Cont.

tmt[a]	IVDDM	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn
	%							ppm			
B	77.67	2.07	0.25	2.50	0.38	0.28	0.14	55	155	14	32
C	72.71	2.56	0.28	2.90	0.35	0.32	0.10	45	100	14	30
A	79.00	2.16	0.31	2.00	0.40	0.40	0.08	55	155	12	32
B	81.20	2.09	0.26	2.80	0.38	0.32	0.06	45	95	14	33
C	62.49	2.11	0.26	3.10	0.32	0.28	0.08	50	100	20	30
A	81.72	3.79	0.39	4.00	0.40	0.38	0.17	85	145	22	37
B	63.70	3.79	0.39	3.50	0.40	0.42	0.14	65	110	18	36
C	82.02	3.61	0.38	3.80	0.40	0.38	0.07	60	120	12	30
A	85.36	3.68	0.39	4.30	0.32	0.30	0.10	35	90	14	31
B	78.97	3.42	0.34	3.20	0.40	0.35	0.13	35	85	12	29
C	84.37	3.37	0.34	3.30	0.38	0.32	0.10	40	70	12	30
A	85.81	3.58	0.38	3.30	0.38	0.38	0.16	55	90	12	32
B	83.17	3.31	0.36	2.70	0.42	0.39	0.10	50	85	11	32
C	51.93	3.43	0.32	3.20	0.32	0.31	0.12	50	100	12	28
A	81.48	3.16	0.32	2.40	0.38	0.40	0.09	35	90	11	30
B	66.78	2.99	0.29	3.60	0.35	0.31	0.10	50	72	10	25
C	53.70	3.26	0.29	2.60	0.38	0.35	0.12	35	85	10	24

a. tmt A = twice daily B = once daily C = three day

APPENDIX D. Effect of two temperature regimes on growth of four kikuyugrass clones

I. OBJECTIVES

Two pilot trials (A and B) were conducted in growth chambers to compare the effects of two temperature treatments (15 and 20 ^{o}C) on the growth of four kikuyugrass clones. Dry matter and leaf area were determined at three and six weeks harvest intervals.

II. MATERIALS AND METHODS

1. Clones

Three clones, from hereon designated as 20, 42 and 48 were selected at the Mealani Experiment Station on the Big Island of Hawaii. A fourth clone (Oahu) was collected on the windward side of the island of Oahu.

2. Trial A

a. sampling material and data collection

Two turfs from each clone were established from vegetative material on 10x33x50 cm flats filled with a vertic haplustoll soil. Harvesting was done at three and six weeks intervals by dividing the flats in half, one half being harvested every three weeks and the second half every six weeks. Turfs were clipped with scissors at a 6 cm stubble height. Leaf area was determined by using a Licor leaf area meter and dry matter was determined by drying the clippings at 70 ^{o}C for 72 hours.

b. Environmental factors

One set of flats was placed in a growth chamber at 15 ^{o}C and the other set at 20 ^{o}C. Vapor pressure deficit was held constant on both chambers by maintaining the relative humidity at 60 and 51% on the 20 and 15 ^{o}C chambers respectively. Photosynthetic photon flux density in the 20 ^{o}C chamber ranged between 480-500 mol photon m-2 s-1 while in the 15 oC chamber it ranged between 460 and 520 mol photon m-2 s-1. Day and night periods of twelve hours were maintained in both chambers. Miracle gro^{R} (15-30-15) was dissolved in water and applied at rates of 136 kg ha^{-1} at six weeks and 280 kg ha^{-1} at twelve and fifteen weeks after the trial had started.

c. Data analyses

Analyses of variance were performed as split plot designs for each harvest interval. Harvests were treated as replications, temperatures as mainplots and clones as subplots. Temperature effect was tested by performing a t-test on the combined data.

3. Trial B

The same turfs were utilized for this trial which was conducted in much the same way as Trial A. Fertilizer was applied at 280 kg ha^{-1} at 0, 6 and 9 weeks. Photosynthetic photon flux density in the 20 ^{o}C chamber ranged between 630-650 mol photon m^{-2} s^{-1} while in the 15 ^{o}C chamber it ranged between 580-660 mol photon m^{-2} s^{-1}. Data was analyzed in the same way as for trial A.

III. RESULTS

1. Trial A

Mean dry weight and leaf area of plants grown at 20 ^{o}C was higher than those of plants grown at 15 ^{o}C. Mean dry weight at 15 ^{o}C (0.81 gm) was significantly lower ($P < 0.01$) than that recorded at 20 ^{o}C (1.58 gm). Mean leaf area at 15 ^{o}C (96.38 cm^2) was significantly lower ($P < 0.05$) than that at 20 ^{o}C (163.72 cm^2).

Analysis of variance for the three week harvest interval showed a significant clone x temperature interaction effect ($P < 0.01$) on dry weight. While there were no differences between the clones at 15 ^{o}C, clone 48 produced significantly less ($P < 0.01$) dry matter at 20 ^{o}C (Fig. 6).

Leaf area accumulation at both temperatures is presented in Figure 7. This variable showed a significant clone x temperature interaction ($P < 0.05$) at a harvest interval of three weeks (Tables 14 and 15).

No significant differences were observed at six week harvest interval (Figures 8 and 9).

2. Trial B

As in trial A, mean dry weight and leaf area were significantly affected by temperature ($P < 0.05$). Mean dry weights recorded at 15 and 20 ^{o}C for the three week harvest interval were 3.40 and 5.49 gm while mean leaf area at these temperatures was 2686.73 and 573.76 cm^2 (Figures 10 and 11).

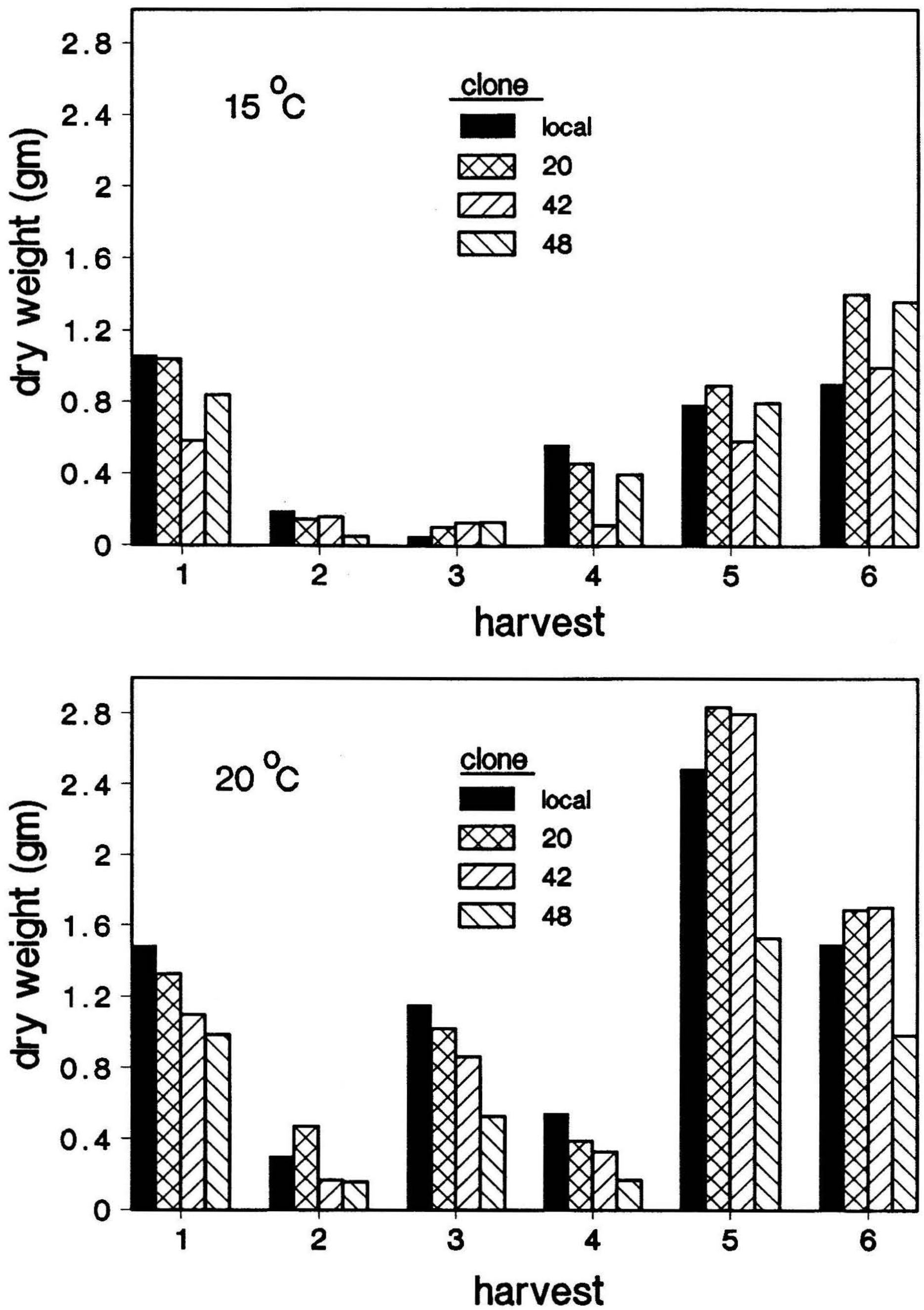


Figure 6. Dry weight accumulation of four kikuyugrass clones grown at two temperatures and harvested every three weeks. Trial A.

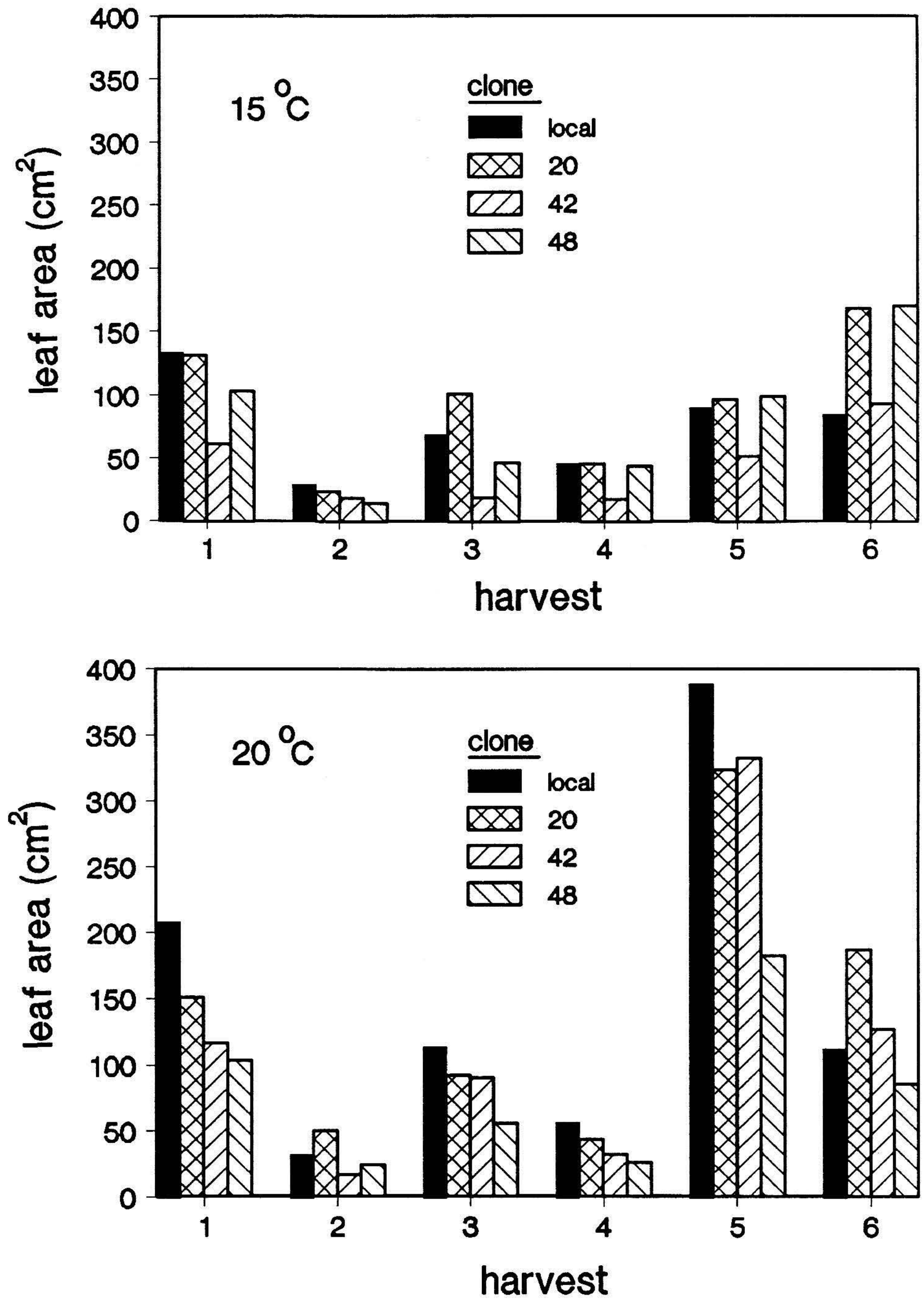


Figure 7. Leaf area accumulation of four kikuyugrass clones grown at two temperatures and harvested every three weeks. Trial A.

Table 14. Mean leaf area accumulation (cm^2) by four kikuyugrass clones grown at 15 ^oC and harvested every three weeks.

N	Clone	Mean leaf area
		(cm^2)
6	20	95.31 a
6	48	80.36 a
6	OAHU	75.89 a
6	42	44.09 b

Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 15. Mean leaf area accumulation (cm^2) by four kikuyugrass clones grown at 20 ^oC and harvested every three weeks.

N	Clone	Mean leaf area
		(cm^2)
6	OAHU	152.63 a
6	20	141.15 a
6	42	119.00 ab
6	48	79.26 b

Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

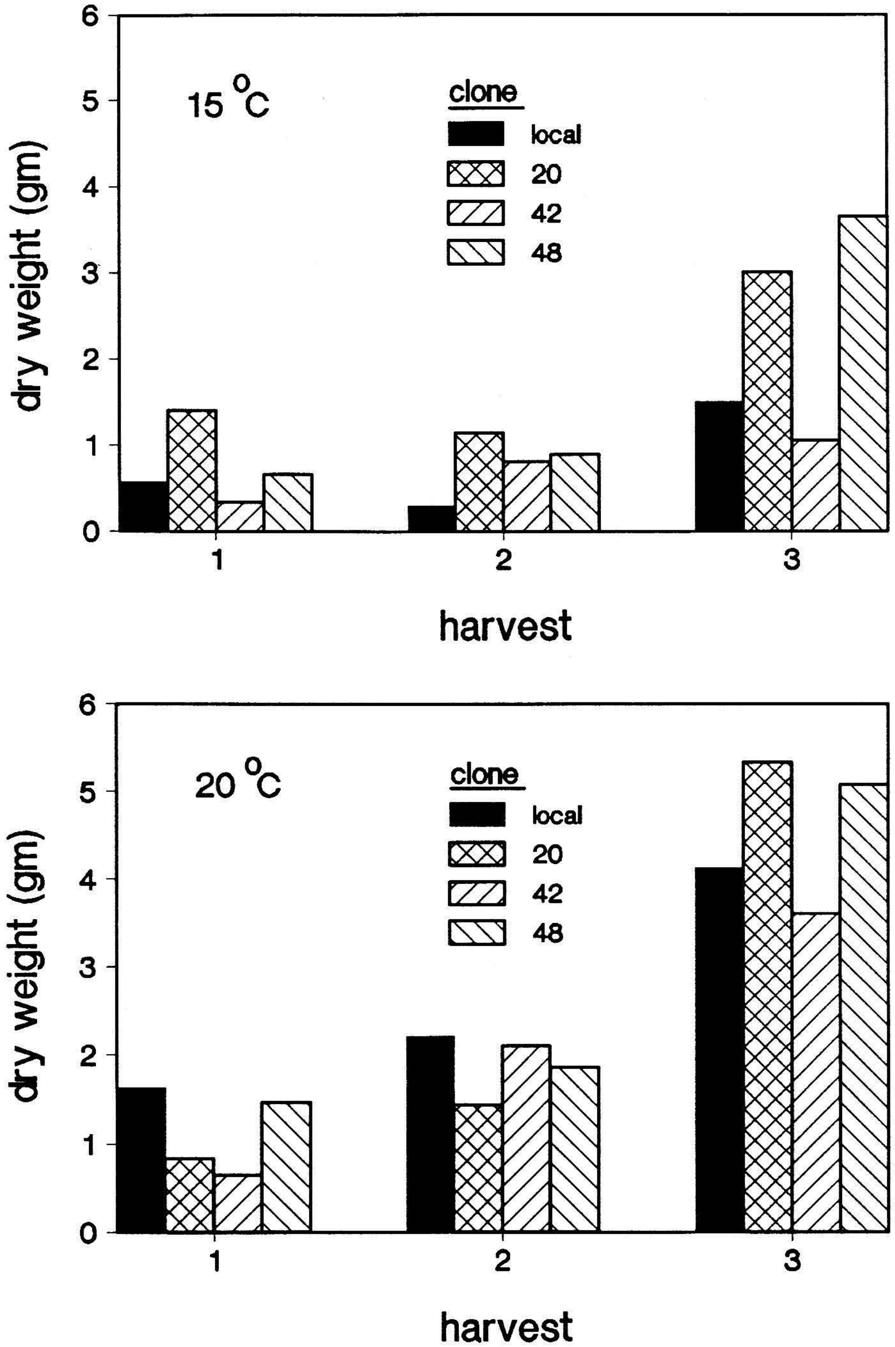


Figure 8. Dry weight accumulation by four kikuyugrass clones grown at two temperatures and harvested every six weeks. Trial A.

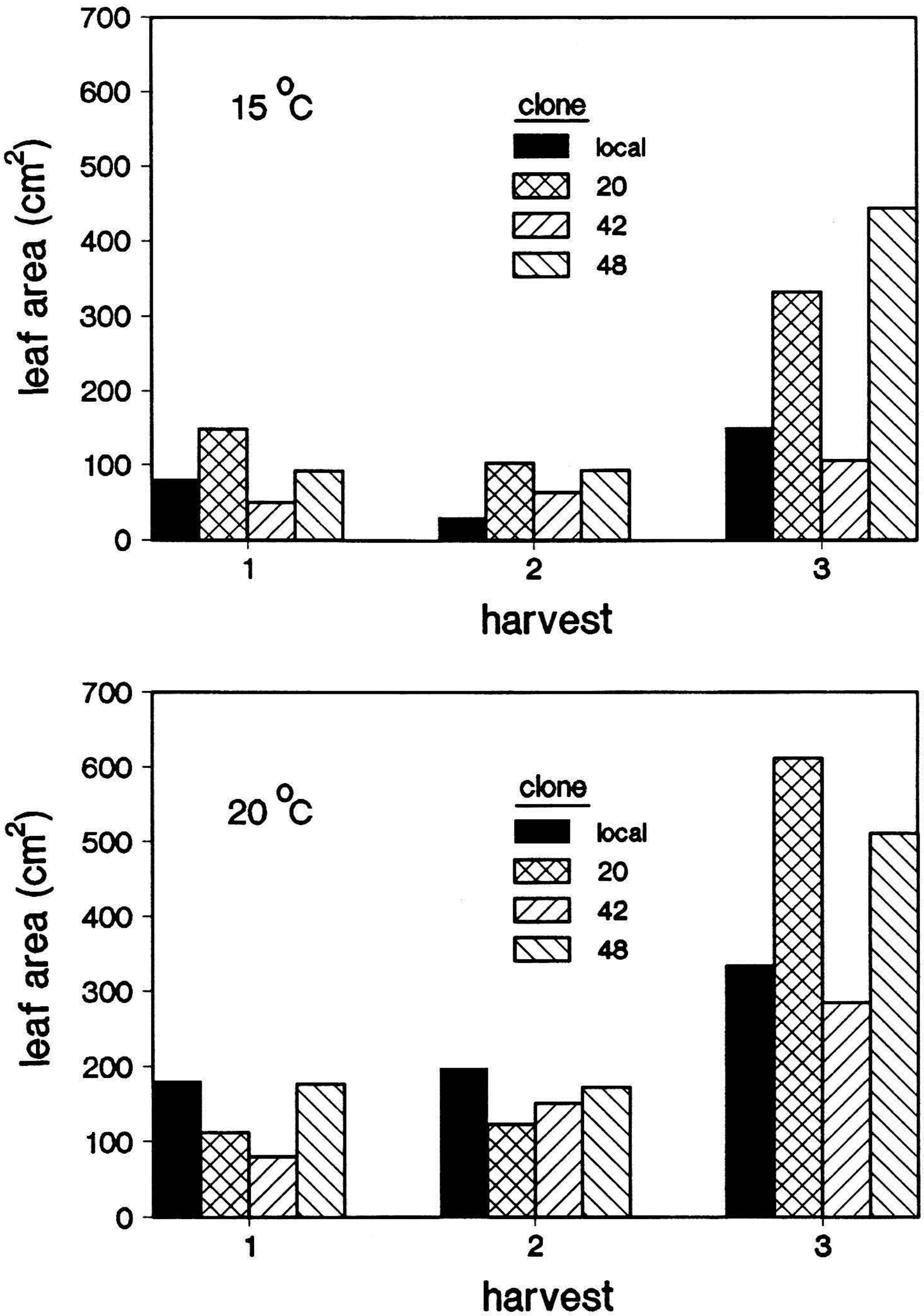


Figure 9. Leaf area accumulation of four kikuyugrass clones grown at two temperatures and harvested every six weeks. Trial A.

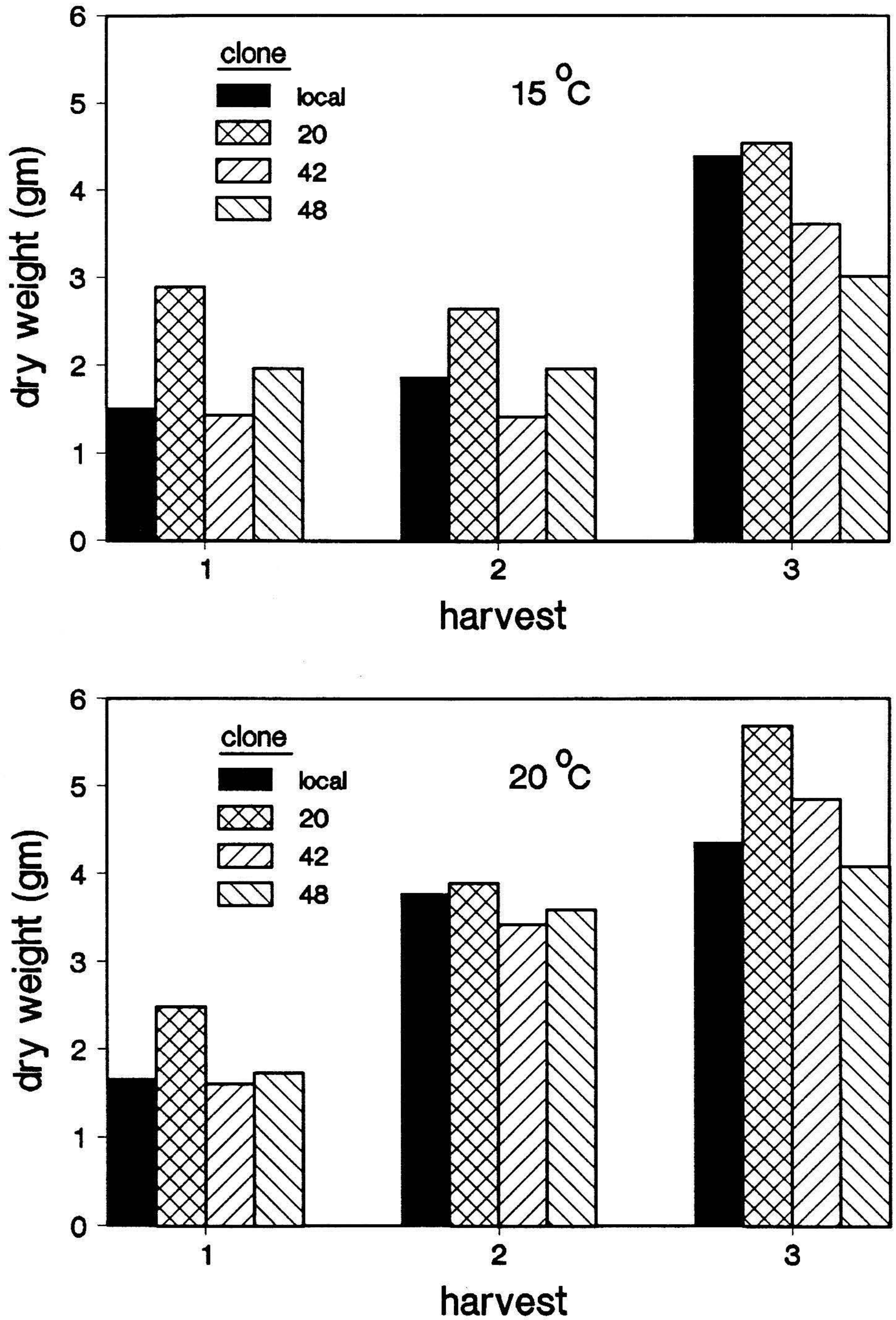


Figure 10. Dry matter accumulation of four kikuyugrass clones grown at two temperatures and harvested every three weeks. Trial B.

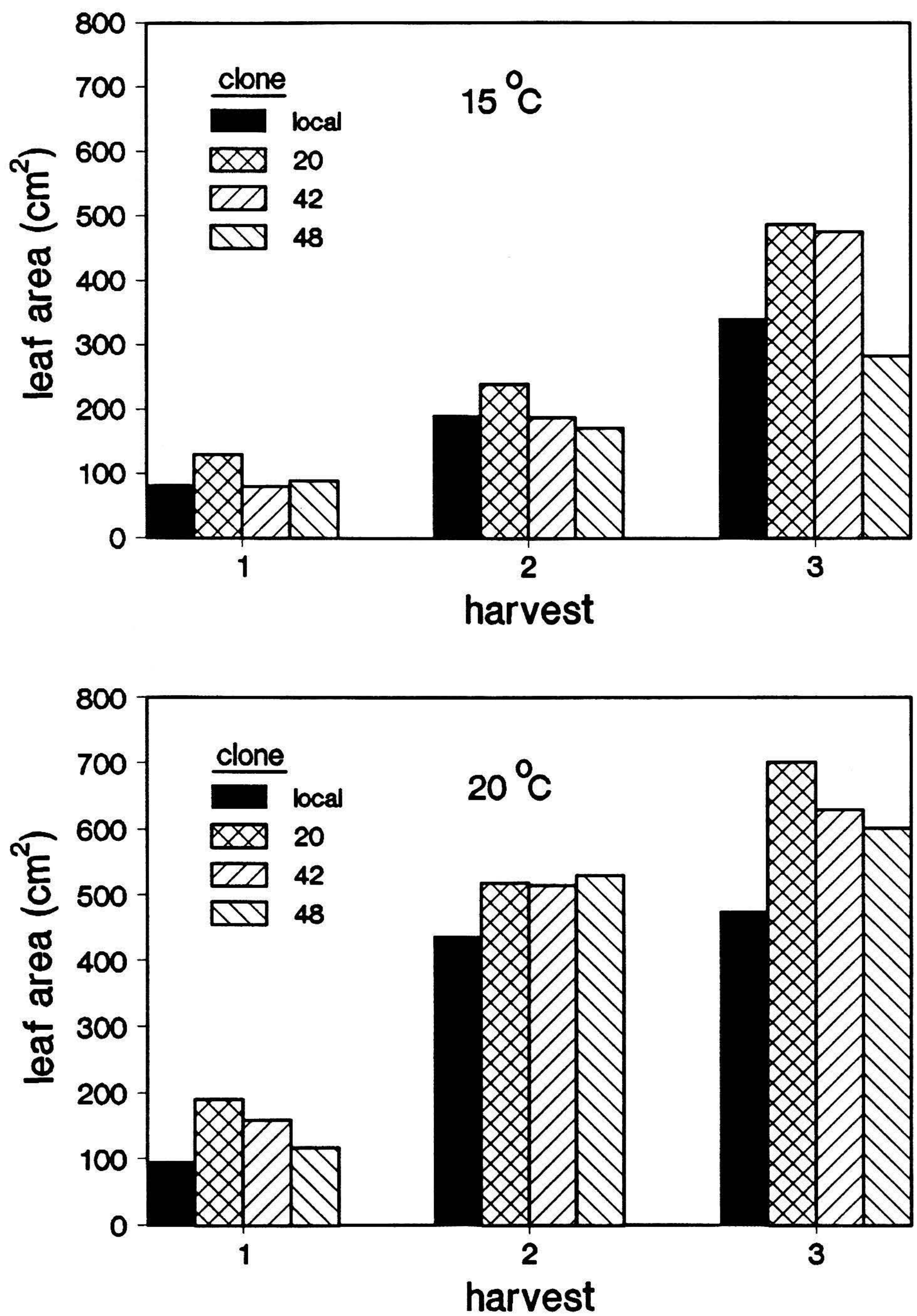


Figure 11. Leaf area accumulation of four kikuyugrass clones grown at two temperatures and harvested every three weeks. Trial B.

Analysis of variance for the three week harvest interval showed statistically significant differences in mean dry weights and leaf areas between clones (Tables 16 and 17). No significant differences between clones were observed in the six week harvest interval (Figures 12 and 13).

Table 16. Mean dry weight (gm) accumulation by four kikuyugrass clones grown at two temperature regimes and harvested every three weeks.

N	Clone	Mean dry weight
		(gm)
8	20	3.22 a
8	OAHU	2.77 ab
8	48	2.57 b
8	42	2.44 b

Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 17. Mean leaf area accumulation (cm^2) by four kikuyugrass clones grown at two temperature regimes and harvested every three weeks.

N	Clone	Mean leaf area
		(cm^2)
8	20	328.09 a
8	42	303.91 ab
8	48	269.31 b
8	OAHU	254.92 b

Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

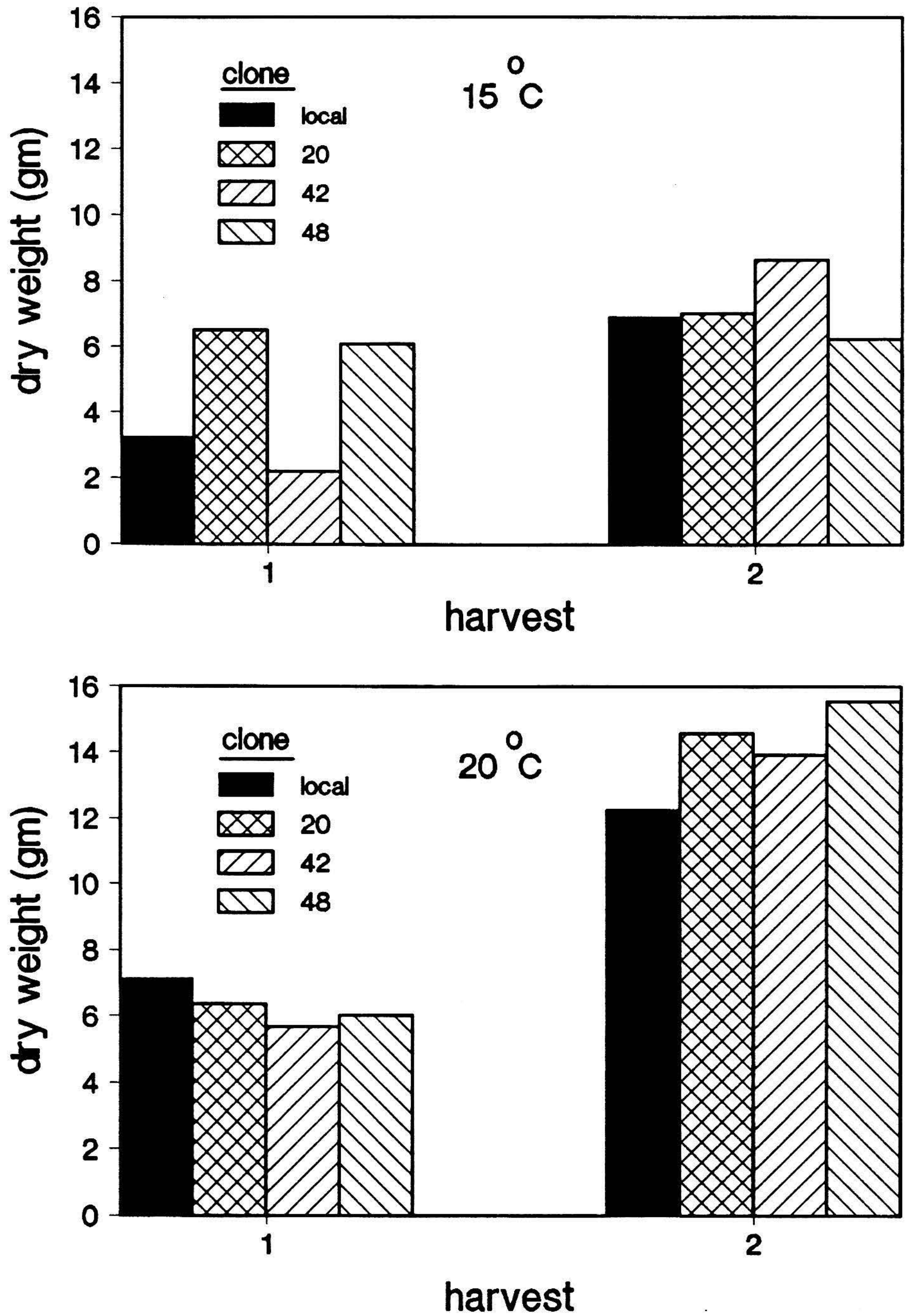


Figure 12. Dry matter accumulation of four kikuyugrass clones grown at two temperatures and harvested every six weeks. Trial B.

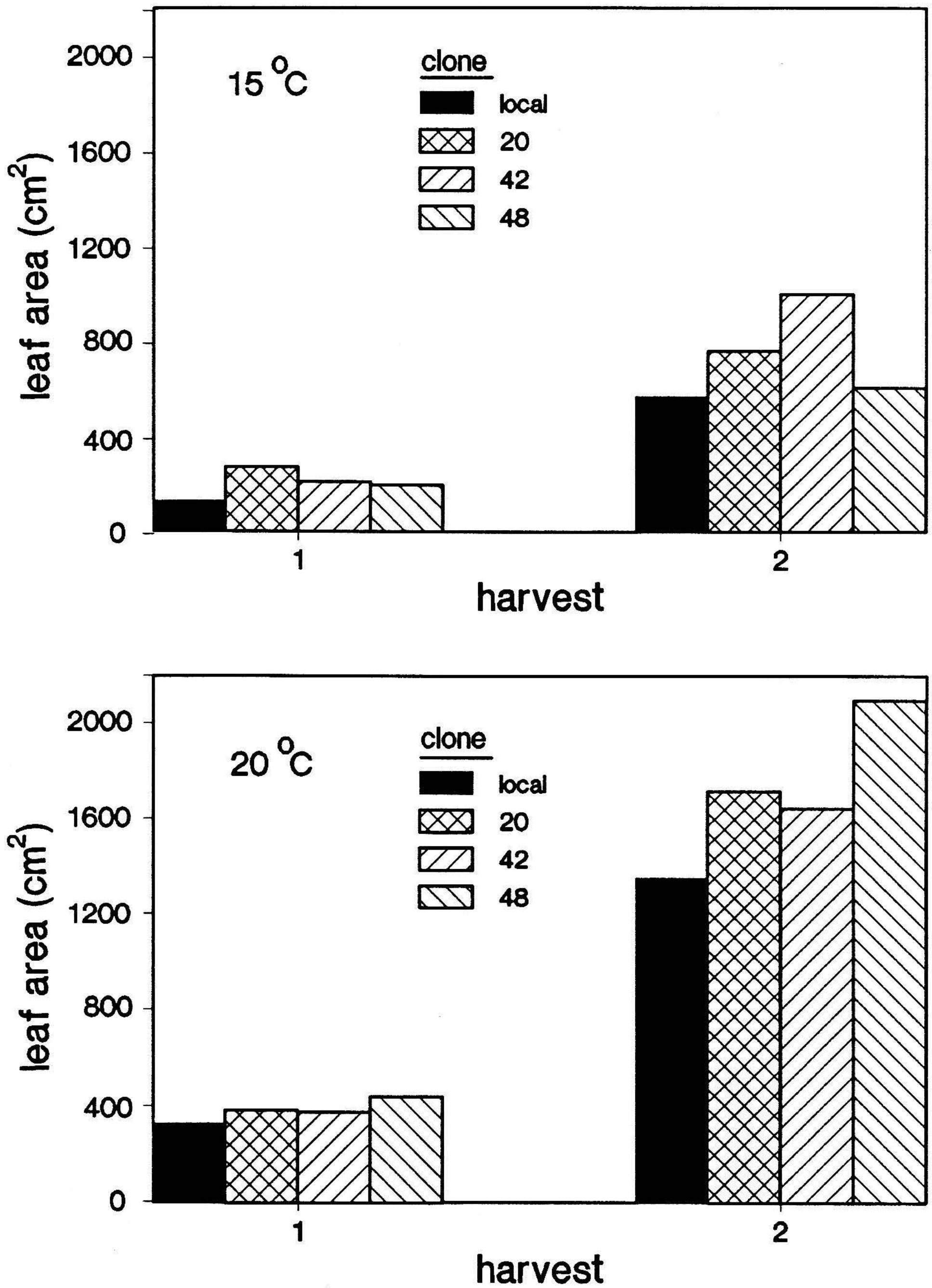


Figure 13. Leaf area accumulation of four kikuyugrass clones grown at two temperatures and harvested every six weeks. Trial B.

IV. DISCUSSION

The experimental design utilized in this experiment did not provide the precision necessary to detect differences between clones. Much of the poor precision is attributed to the lack of replications which would provide an estimate of the variation within clones.

Results obtained were inconsistent from one trial to another. In trial A, clones 20 and 48 seemed to perform better at 15 degrees, clone 48 showed the poorest performance at this temperature in trial B. Clones 20 and 48 appeared to outperform the others under the 20 ^{o}C and six week harvest interval treatment. There were no clear advantages shown by any clone at the 20 ^{o}C-3 week harvest interval or 15 ^{o}C-six week harvest interval treatments. These results could be due to differences in response to the different fertilizer rates applied or to random variation within clones.

Throughout the trials, clones growing at 20 ^{o}C were more responsive to fertilizer application than those at 15 ^{o}C. Clones growing at 20 oC responded dramatically to the fertilizer applied after the fourth harvest (Figures 6 and 7). A decline in growth was seen at the sixth harvest because the plants had already used much of the fertilizer applied. Clones growing at 15 oC did not behave similarly and showed higher growth rates at harvest six compared to harvest five. This result was attributed to the smaller growth response experienced in harvest five which permitted the fertilizer to have a longer residual effect at this temperature.

Visual observation of the plants suggested that those grown at 15 ^{o}C flowered more profusely than those grown at 20 ^{o}C. If this is the case it could be argued that the reduction in dry weight and leaf area observed at 15 ^{o}C is in part due to the use of photosynthates for reproductive and not for vegetative growth.

V. CONCLUSIONS AND RECOMMENDATIONS

Dry matter and leaf area of kikuyugrass clones at 20 oC was at least twice as much of those recorded at 15 oC.

No differences between clones could be detected in this study. Future experiments should therefore include repetitions to increase the degree of precision in detecting differences between clones.

BIBLIOGRAPHY

Arnold, G.W. and Holmes, W. 1958. Studies in grazing management. VII. The influence of strip grazing versus controlled free grazing on milk yield, milk composition, and pasture utilization. The Journal of Agricultural Science 51:248-256.

Awad, A.S., Edwards, D.G. and Milham, P.J. 1976. Effect of pH and phosphate on soluble soil aluminium and on growth and composition of kikuyu grass. Plant and Soil 45:531-542.

Bircham, J.S. and Korte, C.J. 1984. Principles of herbage production. New Zealand Agricultural Science 18:123-126.

Boyd, C.C. 1968. The effect of sulfur, nitrogen, and phosphorus fertilization on the yield and chemical composition of kikuyugrass (Pennisetum clandestinum Hoscht. ex Chiov.). M. S. Thesis. Department of Agronomy and Soil Science, University of Hawaii.

Bryant, H.T., Blaser, R.E., Hammes, R.C.Jr. and Fontenot, J.P. 1970. Symposium on pasture methods for maximum production in beef cattle: Effect of grazing management on animal and area output. Journal of Animal Science 30:153-158.

Campbell, C.M., Garcia, C.W., Nolan, J.C.Jr., Tamimi, Y.N. and Ho-a, E.B. 1971. Beef production from fertilized kikuyugrass pastures in Hawaii. Proceedings Western Section of American Society of Animal Science 22:95-106.

Campbell, C.M. and Ho-a, E.B. 1971. Effect of level of nitrogen fertilization upon the nutritive values of kikuyu and pangola grass. Proceedings Western Section of American Society of Animal Science 22:101-106.

Campbell, C.M., Reimer, D., Nolan, J.C.Jr., Tamimi, Y.N. and Ho-a, E.B. 1977. Grazing management systems for fertilized pastures. Proceedings Western Section of American Society of Animal Science 28:122-123.

Campbell, C.M., Nolan, J.C.Jr., Ho-a, E.B., Kimura, C and Bergin, W.C. 1987. Effects of supplementation on the performance of feeder cattle on Hawaiian ranges. HITAHR. College of Tropical Agriculture and Human Resources. University of Hawaii. Research Extension Series 080.

Carpenter, J.R., Niino-DuPonte, R.Y., Campbell, C.M., Nolan, J.C.Jr., Guyton, R.F., Guyton, J.A. and Ho-a, E.B. 1987. Nutrient composition and digestibility of kikuyugrass (Pennisetum clandestinum) when harvested as grass, silage or hay. Journal of Animal Science 65(supp.1):342.

Carr, D.J. and Ng, E.K. 1956. Experimental induction of flower formation in kikuyu grass (Pennisetum clandestinum Hoscht. ex Chiov). Australian Journal of Agricultural Research 7:1.

Clark, B. and Keener, H.A. 1962. Effect of frequent feeding on weight gain response in young dairy heifers. Journal of Dairy Science 45:1199-1202.

Colman, R.L. and Kaiser, A.G. 1974. The effect of stocking rate on milk production from kikuyu grass pastures fertilized with nitrogen. Australian Journal of Experimental Agriculture and Animal Husbandry 14:155-160.

Ezumah, H.C. 1970. Effect of root temperature, nitrogen and phosphorus nutrition on the growth of kikuyu grass (Pennisetum clandestinum Hoscht. ex Chiov.), pangola grass (Digitaria decumbens Stent.) and green leaf desmodium (Desmodium intortum (Mill.) Urb.). M. S. Thesis. Department of Agronomy and Soil Science, University of Hawaii.

Gibson, J.P. 1981. The effects of feeding frequency on the growth and efficiency of food utilization of ruminants: An analysis of published results. Animal Production 32:275-283.

Goering, H.K. and Van Soest, P.J. 1970. Forage fiber analyses. Apparatus, reagents, procedures, and some applications. USDA-ARS. Agricultural Handbook 379. U.S. Gov. Print. Office, Washington, DC.

Gordon, J.G. and Tribe, D.E. 1952. The importance to sheep of frequent feeding. British Journal of Nutrition 6:89-93.

Hayman, J.M. and Saville, D.J. 1981. Comparison of rotational grazing with set stocking of ewes and lambs in spring on irrigated pasture in Canterbury. New Zealand Journal of Experimental Agriculture 9:11-16.

Hillier, R.J., Perry, T.W., Peart, R.M. and Beeson, W.M. 1968. Effect of timed interval frequent feeding of predominantly corn silage rations to beef steers. Journal of Animal Science 27:227-230.

Holder, J.M. 1967. Milk production from tropical pastures. Tropical Grasslands 1:135-141.

Holmes, W. and El Sayed Osman, H. 1960. The feed intake of grazing cattle. I. Feed intake of dairy cows on strip and free grazing. Animal Production 3:131-139.

Hosaka, E.Y. 1958. Kikuyu grass in Hawaii. University of Hawaii Agricultural Extension Service. Circular 389.

Humphreys, L.R. 1981. Environmental adaptation of tropical pasture plants. Macmillan publishers, London. 261 p.

Ikawa, H., Sato, H.H., Chang, A.K.S., Nakamura, S.,Robello, E.Jr. and Periaswamy, S.P. 1985. Soils of the Hawaii Agricultural Experiment Station, University of Hawaii: Soil survey, laboratory data, and soil descriptions. HITAHR. College of Tropical Agriculture and Human Resources. University of Hawaii. Research Extension Series 022.

Ivory, D.A. and Whiteman, P.C. 1978a. Effect of temperature on growth of five subtropical grasses. I. Effect of day and night temperature on growth and morphological development. Australian Journal of Plant Physiology 5:131-148.

Ivory, D.A. and Whiteman, P.C. 1978b. Effect of temperature on growth of five subtropical grasses. II. Effects of low night temperature. Australian Journal of Plant Physiology 5:149-157.

Kearl, L.C. 1982. Nutrient requirements of ruminants in developing countries. International Feedstuffs Institute. Utah Agricultural Experiment Station. Utah State University, Logan, Utah.

Kilgour, R. and Dalton, C. 1984. Livestock behaviour. A practical guide. Westview Press, Boulder, Colorado. 320 p.

Korte, C.J. 1982. Grazing management of perennial ryegrass/white clover pasture in late spring. Proceedings New Zealand Grassland Association 43:80-84.

Korte, C.J., Chu, A.C.P. and Field, T.R.O. 1987. Pasture production. p. 7-20. In Nicol, A.M. (ed.) Livestock feeding on pasture. New Zealand Society of Animal Production. Occasional Publication 10.

Leung, P. and Smith, B.J. 1984. Economics of Intensive Grazing: A case in Hawaii. HITAHR. College of Tropical Agriculture and Human Resources. University of Hawaii. Research Extension Series 045.

Mannetje, L.'t and Jones, R.J. and Stobbs, T.H. 1976. Pasture evaluation by grazing experiments. p. 194-250. In Shaw, N.H. and Bryan, W.W. (eds.) Tropical pasture research: principles and methods. Commonwealth Agricultural Bureaux, England. Bulletin 51.

Mannetje, L.'t and Pritchard, A.J. 1974. The effect of daylength and temperature on introduced legumes and grasses for the tropics and subtropics of coastal Australia. I. Dry matter production, tillering and leaf area. Australian Journal of Experimental Agriculture and Animal Husbandry 14:173-181.

McDowell, L.R.,Conrad, J.H., Ellis, G.L. and Loosli, J.K. 1983. Minerals for grazing ruminants in tropical regions. Department of Animal Science. Center for Tropical Agriculture. University of Florida and The U.S. Agency for International Development.

McMeekan, C.P. and Walshe, M.J. 1963. The inter-relationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. The Journal of Agricultural Science 61:147-163.

Mears, P.T. 1970. Kikuyu-(Pennisetum clandestinum) as a pasture grass-A review. Tropical Grasslands 4:139-152.

Mears, P.T. and Humphreys, L.R. 1974a. Nitrogen response and stocking rate of Pennisetum clandestinum pastures. I. Pasture nitrogen requirement and concentration, distribution of dry matter and botanical composition. The Journal of Agricultural Science, Cambridge 83:451-467.

Mears, P.T. and Humphreys, L.R. 1974b. Nitrogen response and stocking rate of Pennisetum clandestinum pastures. II. Cattle growth. The Journal of Agricultural Science, Cambridge 83:469-478.

Michell, P. and Large, R.V. 1983. The estimation of herbage mass of perennial ryegrass swards: a comparative evaluation of a rising plate meter and a single probe capacitance meter calibrated at and above ground level. Grass and Forage Science 38:295-299.

Minson, D.J. 1972. The digestibility and voluntary intake by sheep of six tropical grasses. Australian Journal of Experimental Agriculture and Animal Husbandry 12:21-27.

Minson, D.J., Stobbs, T.H., Hegarty, M.P. and Playne, M.J. 1976. Measuring the nutritive value of pasture plants. p. 308-337. In Shaw, N.H. and Bryan, W.W. (eds.) Tropical pasture research: principles and methods. Commonwealth Agricultural Bureaux, England. Bulletin 51.

Mochrie, R.D., Thomas, W.E. and Lucas, H.L. 1956. Influence of feeding equalized intakes on animal response. Journal of Animal Science 15:1256.

Morley, F.H.W. 1981. Management of grazing systems. p. 379-400. In Morley, F.H.M. (ed.) Grazing animals. Elsevier Scientific Publishing Co, Amsterdam.

Morrison, J. 1969. Grasses and legumes at high altitudes in tropical Africa. Herbage Abstracts 39:101-106.

Nada, Y. 1980. Effects of temperature on growth of main tropical pastures grasses. Journal of Japanese Society of Grassland Science 26:165-173.

NRC. 1984. Nutrient requirements of beef cattle. (6th Ed.). National Academy of Sciences-National Research Council, Washington, DC.

O'Sullivan, M. 1984. Measurement of grazing behaviour and herbage intake on two different grazing management systems of beef production. p. 141-150. In Holmes, W. (ed.) Grassland beef production. Martinus Nijhoff Publishers, Boston.

Piggot, G.J. and Morgan, H.M. 1985. Establishing turfs in temperate pastures in hill country. p. 53-54. In Piggot, G.J. (ed.) Kikuyu grass farming for high production. Gallagher Electronics Ltd, Hamilton.

Piggot, G.J. 1986. Methods for estimating pasture dry matter on dairy farms in Northland. Proceedings of the New Zealand Grassland Association 47:243-247.

Putnam, P.A., Gutierrez, J. and Davis, R.E. 1961. Effects of frequency of feeding upon rumen volatile acids, protozoal population, and weight gains in angus heifer calves. Journal of Dairy Science 44:1364-1365.

Quinlan, T.J. and Shaw, K.A. 1975. Kikuyu grass. Queensland Agricultural Journal 101:737-749.

Rakes, A.H., Hardison, W.A., Albert, J., Moore, W.E.C. and Graf, G.C. 1957. Response of growing dairy heifers to frequency of feeding. Journal of Dairy Science 44:1364-1365.

Rakes, A.H., Lister, E.E. and Reid, J.T. 1961. Some effects of feeding frequency on the utilization of isocaloric diets by young and adult sheep. Journal of Nutrition 75:86-92.

Reimer, D., Nolan, J.C.Jr. and Campbell, C.M. 1987. Breeding better beef. 3. Influence of mating system on preweaning performance of calves. HITAHR. College of Tropical Agriculture and Human Resources. University of Hawaii. Research Extension Series 077.

Roberts, M., Cartledge, D.R. and Stern, W.R. 1984. Pasture meter calibration on swards of subterranean clover, annual ryegrass and mixtures of both. The Journal of the Australian Institute of Agricultural Science 50:187-189.

Ruane, J.B. and Raftery, T.F. 1964. An investigation into the merits of intensive rotational grazing. Journal of the British Grassland Society 19:376-380.

Russell, J.S. 1976. Comparative salt tolerance of some tropical and temperate legumes and tropical grasses. Australian Journal of Experimental Agriculture and Animal Husbandry 16:103-109.

Savory, A. and Parsons, S.D. 1980. The Savory grazing method. Rangelands 2:234-237.

Sheath, G.W. 1982. Some effects of grazing duration and sub-division on pasture utilization in hill country. Proceedings New Zealand Grassland Association 43:215-222.

Sheath, G.W. and Bryant, A.M. 1984. Integrating the components of pastoral production: What have we learnt from grazing experiments?. New Zealand Agricultural Science 18:147-152.

Sheath, G.W., Hay, R.J.M. and Giles, K.H. 1987. Managing pastures for grazing animals. p. 65-74. In Nicol, A.M. (ed.) Livestock feeding on pasture. New Zealand Society of Animal Production. Occasional Publication 10.

Sherrod, L.B. and Ishizaki, S.M. 1967. Effects of stage of regrowth and location upon the nutritive value of kikuyu and pangola grass. Proceedings of Western Section of American Society of Animal Science 17:379.

Smetham, M.L. 1973. Grazing management. p. 179-228. In Langer, R.H.M. (ed.) Pasture and pasture plants. A.H. & A.W. Reed Ltd, Wellington.

Smith, B., Leung, P. and Love, G. 1986. Intensive grazing management: forage, animals, men, profits. The Graziers Hui, Hawaii. 350 p.

Squire, J.D. 1985. Isolating the benefits of subdivision. New Zealand Journal of Agriculture 150(9):24-28.

Tamimi, Y.N., Sherrod, S.M., Ishizaki, S.M. and Izuno, T. 1968. The effect of level of nitrogen, phosphorus and potassium fertilization upon beef production on kikuyugrass. Hawaii Agricultural Experiment Station. Bulletin No. 76.

Tamimi, Y. 1971a. Responses of kikuyu and pangola grasses to nitrogen, phosphorus and potassium. I. Effect of low rates. p. 76-84. In Proceedings 7th annual beef cattle field day. University of Hawaii. Cooperative Extension Service. Miscellaneous Publication 81.

Tamimi, Y. 1971b. Responses of kikuyu and pangola grasses to nitrogen, phosphorus and potassium. II. Effects of high rates. p. 85-92. In Proceedings 7th annual beef cattle field day. University of Hawaii. Cooperative Extension Service. Miscellaneous Publication 81.

Tamimi, Y.N. and Matsuyama, D.T. 1975. Fertilization of grass-legume mixture. p. 30-35. In Proceedings 9th beef cattle field day. Cooperative Extension Service. University of Hawaii. Miscellaneous Publication 128.

Tamimi, Y.N., Campbell, C.M., Matsuyama, D.T. and Ho-a, E.B. 1984. Productivity and feasibility of kikuyu grass-legume pastures for beef cattle production in Hawaii. p. 25-29. In Proceedings 18th-19th Mealani beef cattle field day. HITAHR. College of tropical agriculture and human resources. University of Hawaii. Research Extension Series 050.

Urata, U. 1972. Pangola and kikuyugrass breeding. p. 79-81. In Proceedings 8th annual beef cattle field day. Cooperative Extension Service. University of Hawaii. Miscelaneous Publication 97.

Urata, U. 1981. Kikuyugrass breeding in Hawaii. p. 33-34. In Proceedings 16th Mealani beef cattle field day. HITAHR. College of tropical agriculture and human resources. University of Hawaii. Research extension series 023.

Vickery, P.J., Bennett, I.L. and Nicol, G.R. 1980. An improved electronic capacitance meter for estimating herbage mass. Grass and Forage Science 35:247-252.

Voisin, A. 1959. Grass productivity. Philosophical Library Inc, New York.
353 p.

Walton, P.D., Martinez, R. and Bailey, A.W. 1981. A comparison of continuous and rotational grazing. Journal of Range Management 34:19-21.

Wheeler, J.L. 1962. Experimentation in grazing management. Herbage Abstracts 32:1-7.

Whiley, L.E. 1985. Establishment for erosion control. p. 50-52. In: Piggot, G.J. (ed.) Kikuyu grass farming for high production. Gallagher Electronics Ltd, Hamilton.

Whiteman, P.C. 1980. Tropical pasture science. Oxford University Press, Oxford. 392 p.

Whitney, A.S. 1974a. Growth of kikuyugrass (*Pennisetum clandestinum*) under clipping. I. Effects of nitrogen fertilization, cutting interval, and season on yields and forage characteristics. Agronomy Journal 66:281-287.

Whitney, A.S. 1974b. Growth of kikuyugrass (*Pennisetum clandestinum*) under clipping. II. Regrowth characteristics in relation to nitrogen fertilization and climate. Agronomy Journal 66:763-767.

Wilson, G.P.M. 1970. Method and practicability of kikuyu grass seed production. Proceedings of the 11th International Grassland Congress, Surfer's Paradise. pp.312-315.

Wilson, G.P.M. and Hennessy, D.W. 1977. The germination of excreted kikuyugrass seed in cattle dung pats. The Journal of Agricultural Science, Cambridge 88:247-249.

Winer, B.J. 1971. Statistical principles in experimental design. McGraw-Hill, New York. 907 p.

Younger, V.B. 1961. Low temperature induced male sterility in male fertile *Pennisetum clandestinum*. Science 133:577.